final technical report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume II - book 1
part I — mission requirements

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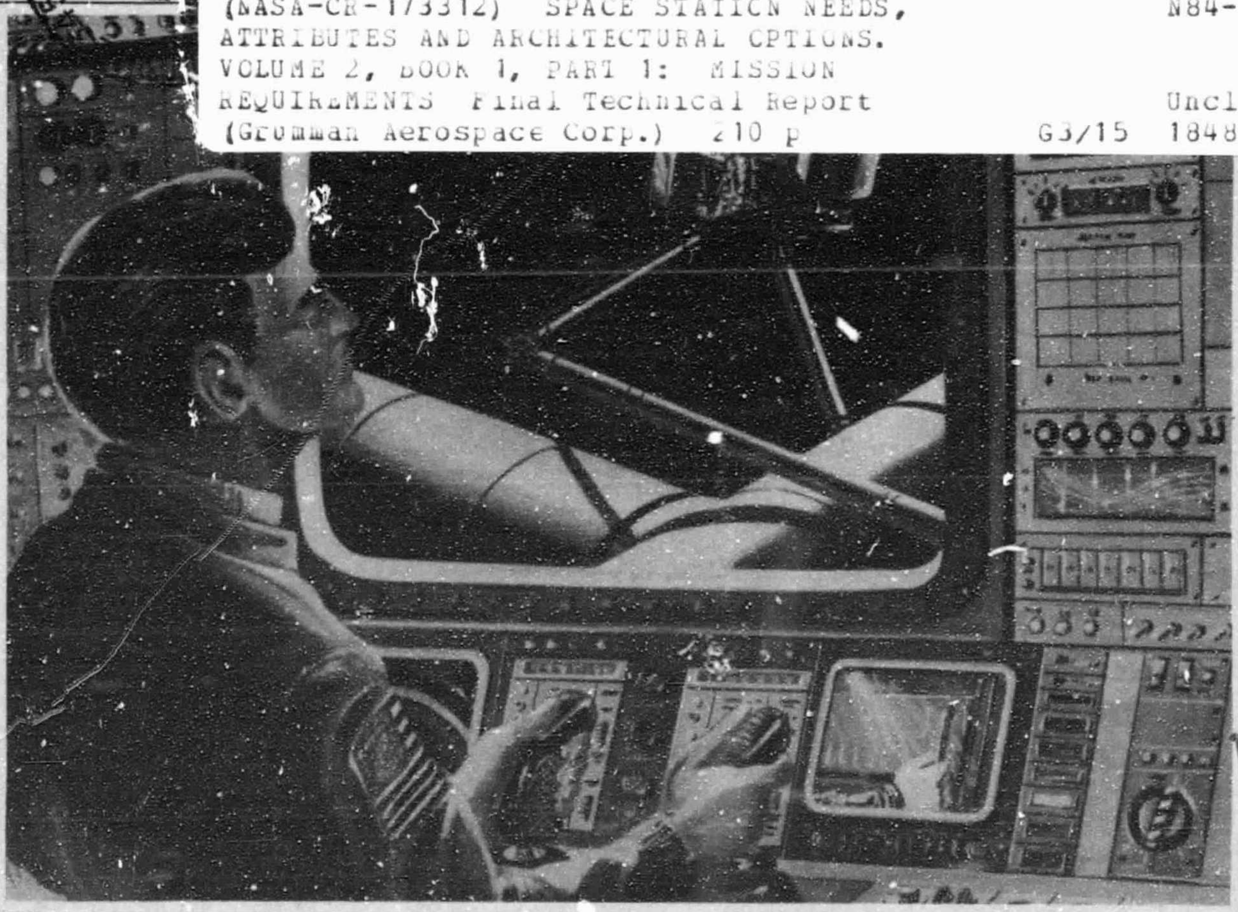

GRUMMAN

COMSAT GENERAL

GENERAL ELECTRIC

final technical report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume II - book 1
part I — mission requirements

prepared for
National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546

under contract NASW-3685
Space Station Task Force
Contracting Study Project Manager — E. Brian Pritchard

by

Grumman Aerospace Corporation
Bethpage, New York 11714

report no. SA-SSP-RP008

20 April 1983

PREFACE

This book consists of four parts and contains the results of studies to develop realistic system architectural concepts and implementation plans for a manned Space Station and its elements. The studies were based on and interated with the mission requirements presented in Book 1 and the programmatics covered in Volume II, Book 3.

Part I of this book describes the approach used to develop the architecture, and presents the results. In addition, the studies performed for the major subsystems and the program evolution are persented.

The results of a special emphasis study of the Space Station Information Management System, by the Space Station Division of General Electric, under subcontract to Grumman are presented in Part II of this volume.

Part III contains the results of a special emphasis study on the Communication Subsystem by COMSAT General, under subcontract to Grumman.

Part IV contains supportive architectural information supplied by MBB/ERNO, Dornier and British Aerospace.

FOREWORD

The study of Space Station Needs, Attributes, and Architectural Options was an eight month effort, focusing on manned space activities during the 1990s that would either require or materially benefit from a Manned Space Station. This study was performed by Grumman Aerospace Corporation, with General Electric and COMSAT General as teammates, under contract NASW-3685 for the National Aeronautics and Space Administration Headquarters' Space Station Task Force.

The NASA Contracting Officer's Representative and Project Study Manager was Mr. E. Brian Pritchard. Technical monitor for the DoD Space Station Working Group was Capt. James Schiermeyer AFSD/XR, who was assisted by Dr. John Baker of the Aerospace Corporation.

This contract was performed within Grumman's Space Station Programs organization directed by Dick Kline. The Grumman Project Study Manager was Ron McCaffrey, who in turn was assisted by Deputy Project Manager Joe Goodwin and Assistant Project Managers Al Alvarado of General Electric and Phil Caughran of COMSAT General. Grumman Task Leaders are:

- Marty Finkelman - Mission Requirements
- Don Stein - Concept Development
- Jim Wilder - Cost and Programmatics
- Ron Boyland - DoD Assignment

The results of the overall study are described by the following final report documentation.

- Volume I, Executive Summary, Report No. SA-SSP-RP007, 20 April 1983
- Volume II, Technical Report No. SA-SSP-RP008, 20 April 1983
  - Book 1 - Mission Requirements
  - Book 2 - Mission Implementation Concepts
  - Book 3 - Cost and Programmatics
  - Book 4 - Military Mission Assessment (Classified)
- Final Briefing, Report No. SA-SSP-RP009, 5-9 April 1983
  - Part 1 - Summary

- Part 2 - Mission Requirements
- Part 3 - Commercialization
- Part 4 - Technology Development
- Part 5 - Systems
- Part 6 - Costing
- Part 7 - DoD Summary (Classified)
- Part 8 - National Security (Classified).

Significant contributions were made to the Grumman study effort by their two teammates:

- COMSAT General defined space station requirements and benefits for commercial communication satellites and the onboard RF communication subsystem. This work was performed within COMSAT Generals' Engineering and Systems Integration organization directed by Mel Savage
- General Electric, in turn, defined space station requirements and benefits for selected areas of science and applications, commercial processing and remote sensing, and national security missions. In addition, they defined architectural concepts for the data management subsystem. This work was performed within General Electrics' Advanced Earth Observation Programs organization managed by Lew Beers.

Technical progress was periodically reviewed during the study by a seven member Constituency Development Council (CDC). This group met on an "ad hoc" basis to provide senior management/evaluation perspective before each presentation. Members of the CDC include:

- Dan Huebner, Chairman, Grumman Sr. VP Marketing and Advanced Technology
- Fred Haise, Grumman VP Space Programs
- Al Rosenberg, General Electric VP & General Mgr Space System Division
- Bill Houser, COMSAT General VP System Technology Services
- Grant Hedrick, Grumman Presidential Asst. for Corporate Technology
- B/Gen. Dick Rumney (Retired)
- V/Adm. Forrest Petersen (Retired)

The CDC also provided guidance to parallel corporate funded activities to develop space station advocates and constituents within non-aligned commercial

companies. Lou Hemmerdinger, Manager for Space Station Utilization, led Grumman's efforts in this area. Jack Dickinson led similar activities at General Electric. Grumman and General Electric focused on individualized meetings with prospective clients in the pharmaceuticals, metals and semiconductor industries; Clarance Catoe of COMSAT, surveyed the telecommunications industry.

We wish to acknowledge contributions from British Aerospace, MBB/ERNO and Dornier Systems for information on European mission requirements and hardware definitions, for which each company is particularly competent.

Questions regarding this study should be directed to:

Mr. E. Brian Pritchard MFA-13
Contracting Study Project Manager
NASA Headquarters
Space Station Task Force
Washington, D.C. 20546

or

Mr. Ronald W. McCaffrey
Space Station Project Manager
Grumman Aerospace Corporation
Bethpage, N.Y. 11714

KEY SPACE STATION PERSONNEL

	GRUMMAN	GENERAL ELECTRIC	COMSAT GENERAL
Council Review	D. Huebner, Sr. VP F. Haise, VP I.G. Hedrick, Pres. Asst B/Gen. R. Rumney (Ret) V/ADM F. Petersen (Ret)	A. Rosenberg VP	W. Houser, VP
Program Review	R. Kline	L. Beers	M. Savage
Project Mgr	R. McCaffrey		
Deputy & Asst Mgr	J. Goodwin	A. Alvarado	P Caughran
Mission Req Leader (Task 1)	M. Finkelman		
Mission Integration	W. Schoen	C. Braunwarth	
Materials Processing	D. Larsen	R. Frost	
Communications	W. Schoen		C. Pentlicki* G. Welti* D. Spinivas*
Science & Applications	R. Pratt T. Hilgeman W. Egan	R. White A. Park M. Bortner	
Military	R. Boyland V. Priebe J. Schultz D. Sullivan J. Corbett	J. McGlinchey	
System Reqmts	R. Pratt		
Proximity Operations	R. Adornato		

*Comsat Labs

	GRUMMAN	GENERAL ELECTRIC	COMSAT GENERAL
Concept Devel Leader (Task 2)	D. Stein		
Concept Design	S. Sherman		
Crew System Design	G. Harms		
Communication	F. Savarese	L. Jones	C. DeViex H. Song
Data Management	E. Ramirez	H. Kraiman R. Barnes E. Heater R. O'Connell	
ECLS	F. Abeles		
GN&C	R. Olsen		
Electrical Power	H. Siegel		
Weights	J. Sims		
Cost Programmatics Leader (Task 3)	J. Wilder		
Cost Analysis	A. Kallas K. Hale R. Black	A. Cohen	
Test	G. Meyers		
DoD Assignment Leader (Task 4)	R. Boyland		
Mission Analysis	J. Schultz D. Sullivan T. Hilgeman	F. Vicente	
Models	V. Priebe W. Brunnig		
Radiation	S. Miluschewa M. Stauber		
Utilization Mgr	L. Hemmerdinger	J. Dickinson	
Marketing	S. Abraham		
Research	D. Larsen		
Prospectus/Industry Survey			C. Catoe

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GLOSSARY

AC	Alternating Current
ACS	Attitude Control Subsystem
ADA	High Level Language
ADF	Automatic Direction Finder
AgZn	Silver Zinc
A/L	Airlock
Amp-Hr	Ampere Hour
Ant	Antenna
AXAF	Advanced X-ray Astrophysics Facility
BER	Bit Error Rate
BOL	Beginning of Life
BPD	Bits Per Day
BPS	Bits Per Second
BW	Bandwidth
C&D	Controls & Displays
C&T	Communications & Tracking
C&W	Caution & Warning
CCTV	Closed Circuit Television
CER	Cost Estimate Relationship
C.G.	Center of Gravity
CH4	Methane
CMD	Command
CMG	Control Moment Gyro
CMOS	Complimentary Metal Oxide Semiconductor
C/O	Check Out
CO_2	Carbon Dioxide
COMM	Communication
COMSEC	Communications Security

CPU	Computer Processor Unit
CRC	Cycle Redundant Code
CRT	Cathode Ray Tube
CY	Calendar Year
DB	Decibel
DBMS	Data Base Management System
D/BS	Docking/Berthing System
DC	Direct Current
DDT&E	Design Development Test & Evaluation
Deg	Degree(s)
DF	Direction Finding
Dia	Diameter
DMS	Data Management Subsystem
DoD	Department of Defense
DOD	Depth of Discharge
DOF	Degrees of Freedom
DOMSAT	Domestic Satellite
DRIRU	Dry Rotor Inertial Reference Unit
EC/LSS	Environmental Control/Life Support Subsystem
EMU	Extra Mobility Unit
EPS	Electrical Power Subsystem
ERP	Effective Radiator Power
ESS	Evolved Space Station
EVA	Extra Vehicular Activity
FEC	Forward Error Correction
FF	Free Flyer
FOV	Field of Vision
FSS	Flight Support Station
FY	Fiscal Year
GaAs	Gallium Arsenide
GAC	Grumman Aerospace Corporation

GEO	Geosynchroneous Earth Orbit
GFE	Government Furnished Equipment
GHz	Gigahertz
GN&C	Guidance, Navigation, & Control
GPS	Global Positioning Satellite
GS	Ground Station
GSE	Ground Support Equipment
GSTDN	Ground Satellite Tracking & Data Network
H_2	Hydrogen
H_2O	Water
HM No. 2	Habitat Module Number 2
HOL	High Order Language
HPA	Handling & Positioning Aid
HSM No. 1	Habitat/Subsystem Module Number 1
HZ	Hertz (Cycles Per Second)
I/F	Interface
IACO	Integration, Assembly & Checkout
IFF	Identification Friend or Foe
IOC	Initial Operational Capability
IPS	Instrument Pointing System
Isp	Specific Impulse, Sec.
ISS	Initial Space Station
IVA	Intra Vehicular Activity
KBS	Kilobytes Per Second
kg	Kilogram
km	Kilometer
KOPS	Kilo Operations Per Second
KSA	Ku-Band Special Acess
KW, Kw	Kilowatt
KWe	Kilowatts Electrical
KW-Hr	Kilowatt-Hour

L-Band	L-Band Frequency
LEO	Low Earth Orbit
LH_2	Liquid Hydrogen
LiOH	Lithium Hydroxide
L/M	Logistics Module
L/M/P	Logistics Module Pallet
LMSC	Lockheed Missile & Space Company
LO_2	Liquid Oxygen
LOS	Line of Sight
L/V	Local Vertical
M	Meter
M^2	Square Meters
M^3	Cubic Meters
MB	Megabytes
MBA	Multiple Beam Array
MHz	Mega Hertz (Million Cycles)
MISC	Miscellaneous
MMI	Man/Machine Interface
MMU	Maned Maneuvening Unit
MODEM	Modulator/Demodulator
MOTV	Manned Orbital Transfer Vehicle
MRWS	Manned Remote Work Station
MSFC	Marshall Spacecraft Flight Center
NASA	National Aeronautics & Space Administration
N_2	Nitrogen
N/A	Not Applicable
NiCd	Nickel Cadmium
NiH_2	Nickel Hydrogen
N MI	Nautical Mile
N-M	Newton-Meter
N-M-S	Newton-Meter-Sec

O_2	Oxygen
OaS	Operations and Support (Cost)
OCP	Open Cherry Picker
OPS	Operations
ORU	Orbital Replaceable Unit
OTV	Orbital Transfer Vehicle
PAM-D	Payload Assist Module-D
P^3	Programmable Power Processor
PCC&D	Power Control, Conversion, & Distribution
P/L	Payload
POP	Perpendicular to Orbit Plane
PPU	Power Processing Unit
POV	Proximity Operations Vehicle
PROP	Propulsion
Pwr	Power
R&D	Research and Development
RCS	Reaction Control Subsystem
RDT&E	Research Development Test & Engineering
Rec	Recreation
RF	Radio Frequency
RFC	Regenerative Fuel Cell
RMS	Remote Manipulator System
S/A	Solar Array
S-Band	S-Band Frequency
SAWD	Solid Amine Water Desorbed
SCS	Stability and Control Subsystem
SEPS	Solar Electric Propulsion System
Si	Silicone
SIU	Signal Interface Unit
SIMOP	Simulataneous Operation
SIRTF	Shuttle Infrared Telescope Facility

SOA	State of the Art
SRM	Solid Rocket Motor
SS	Space Station
SSA	S-Band Single Access
STS	Space Transport System
TBD	To Be Determined
TCC	Transformer Coupled Converter
TDAS	Tracking and Data Acquisition Satellite
TDRSS	Tracking & Data Relay Satellite Sytems
TFU	Theoretical First Unit (Cost)
TH	Transportation Harbor
TIP	Tended Industrial Park
TIMES	Thermo-Electric Integrated Membrane Evaporation System
TMS	Teleoperator Maneuvering System
TPP	Tended Polar Platform
TV	Television
UHF	Ultra-High Frequency
VCD	Vapor Compression Distillaton
VHSIC	Very High Speed Integration Circuits
Vdc	Volts-Direct Current
VV	Velocity Vector
W/M	Waste Management
WSGT	White Sands Ground Terminal
WTR	Western Test Range

1 - INTRODUCTION

Analysis of Space Station requirements encompasses the full range of possible space missions covered by U.S. national security, plus domestic and foreign missions that include commercial, science and applications, and technology development. These were analyzed to identify those missions which need or can gain a significant benefit from the availability of a Space Station. As shown in Fig. 1-1, the major inputs to the study were derived from prior studies on NASA Space Stations/related mission systems, NASA and DoD Space System Technology Models, related foreign mission studies, data provided by NASA during this study and ideas from our Constituency Development Council.

As the beginning of this study, over 100 missions were analyzed to identify which missions would most likely benefit from a Space Station if it were used in any of three roles: 1) support mission development (R&D or proof of concept); 2) support mission space operations (on orbit assembly, deployment and servicing/ retrieval); and 3) support active mission operations (earth observations, astrophysics, etc). These missions were screened against generic Space Station capabilities (long-duration, on board storage, manned attendance, ample power, etc) to identify candidate missions for further analysis and quantification of benefits. This was an iterative process. Time-phased mission sets were defined for the 1990 to 2000 timeframe for each class of missions. For example, commercial mission schedules and activity levels are projected from market surveys and analysis; science and application missions, in turn, are based on NASA programs and plans with schedules adjusted to meet projected budget constraints; whereas DoD missions and schedules are based on published DoD plans and private discussions. Candidate Space Station missions were then grouped according to orbit need.

The major outputs of the Mission Requirements task were to: 1) establish a single Baseline Mission Model; 2) use the Baseline Model to develop a consistent set of Space Station mission-related requirements; 3) identify and evaluate any attractive alternatives to the Baseline Model.

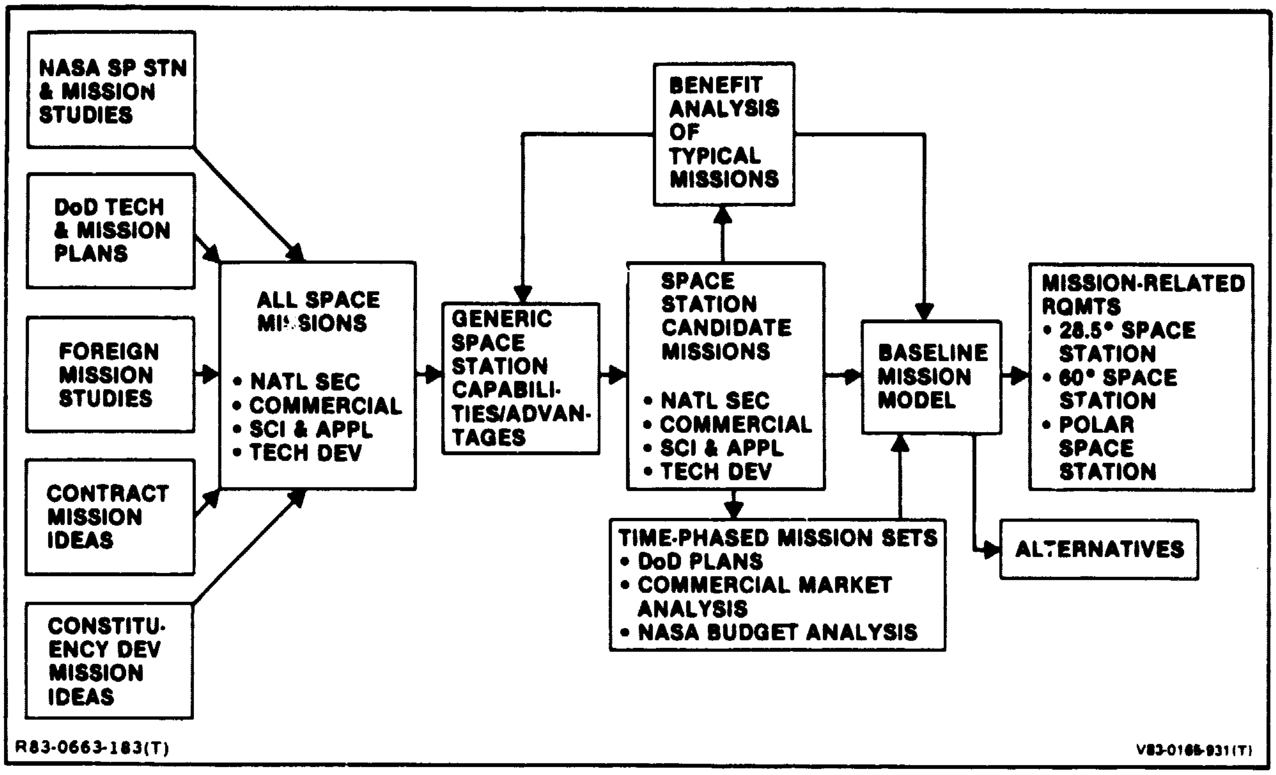

Fig. 1-1 Mission Model Logic Flow

Part I of this document contains the following sections:

- **Section 2** describes the Baseline Mission Model which was used to develop the Space Station mission-related requirements
- **Section 3** contains a detailed description of the 90 civil missions that were evaluated during this study, including the 62 missions that formed the Baseline Model
- **Section 4** defines the mission-related requirements for the Space Station Baseline and relates these requirements to Space Station architectural development
- **Section 5** discusses mission-related sensitivity analyses.

Volume II Book 1 also contains the following parts, each under separate cover:

- **Part II**, prepared by General Electric (GE), details the requirements for several of the missions that were analyzed by GE personnel
- **Part III**, prepared by COMSAT General is entitled, "Manned Space Station Relevance To Commercial Telecommunications Satellites"
- **Part IV**, prepared by Grumman, GE, and COMSAT personnel, contains the Payload Element Mission Data Sheets.

A complete description and analysis of the U.S. national security missions is contained in Volume II Book 4.

2 - BASELINE MISSION MODEL

The Space Station Baseline Mission Model, described in this section, comprises all the missions/payloads that were utilized to develop the integrated Space Station mission-related requirements (described in Section 4).

All missions/payloads which had no preferred orbital characteristics were placed in a 28.5° inclination orbit since this results in the lowest transportation cost to orbit. Many payloads required polar orbits to satisfy their mission objectives. Several payloads desired mid-inclination orbits where a 57° inclination orbit would have been satisfactory. The projected mission payload weights to both polar and 57° inclined orbits for the Baseline Mission Model are shown in Fig. 2-1. Although Shuttle transportation costs to a 57° inclination orbit are about one-half of the Shuttle transportation costs to polar orbit, there were not enough missions that could function in a 57° orbit to justify a permanent presence at that inclination. All of these missions were integrated with the polar orbit missions for the Baseline MIssion Model.

A summary of the Science and Application and Commercial Missions that formed the Baseline Mission Model is shown in Fig. 2-2. These 62 missions are discussed in this section.

In addition, the projected satellite traffic to geosynchronous orbit (GEO) was also considered as part of the Baseline Model. A total of 131 commercial communication and military satellites were included in the Baseline Mission Model.

Section 3 contains detailed descriptions of the 90 missions that were evaluated during this study including the 62 missions that formed the Baseline Mission Model.

2.1 GROUNDRULES AND ASSUMPTIONS

The following basic groundrules and guidelines were used in the performance of this study:

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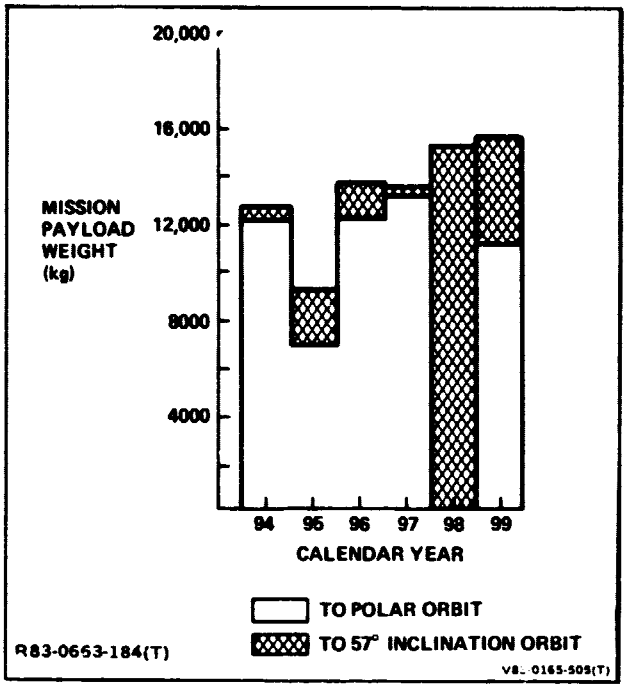

Fig. 2-1 Mission Payload Weights to High Inclination Orbits

MISSIONS	INCLINATION			TOTALS
	28.5°	57°	POLAR	
SCIENCE & APPLICATION	(30)	(0)	(18)	(48)
• ASTROPHYSICS	9		2	11
• PLANETARY	6			6
• LIFE SCIENCES	5			5
• MATERIAL PROCESSES	4			4
• SOLAR TERRESTRIAL	3		10	13
• GLOBAL ENVIRONMENT	2		6	8
• RESOURCE OBSERVATION	1			1
COMMERCIAL	(13)	(0)	(1)	(14)
• COMMUNICATIONS	4	—	—	4
• MATERIAL PROCESSES	9	—	—	9
• EARTH OBSERVATION			1	1
R83-0663-185(T)		GRAND TOTAL		62

Fig. 2-2 Baseline Mission Model Summary Civil Missions

- The permanent facilities defined during this study will be Shuttle launched and Shuttle tended, as required. The Space Shuttle User's Handbook shall be used to provide the associated guidelines
- Potential missions of interest shall include domestic and foreign science, applications and commercial users, as well as U.S. national security and space operations missions
- Time-period of interest shall be the later 1980s through the year 2000
- Missions identified and included in the study results shall have identified users, and include the specific source of user input. The validity of the missions and requirements for the Space Station developed under this study will be determined in part by the traceability of user data
- Although the study will primarily consider the requirements for a permanent manned Space Station in low earth orbit, requirements for the full range of potential future support systems shall be established
- The Tracking and Data Relay Satellite System (TDRSS) will be the primary space-to-ground RF communications interface for Space Station operations. The TDRSS User's Guide shall be used to define the Space Station interfaces
- Development of Space Station attributes and architectural options should consider the accommodation of all feasible missions with a single Space Station in the 1990 time-frame. The evolutionary growth of the system could require consideration of multiple space facilities.

Over 100 missions were initially considered for applicability to the Space Station Program. After an initial screening process, approximately 90 mission applications were subjected to an evaluation/filtering process which resulted in the Baseline Mission Model.

The following mission-related groundrules and assumptions were established early in the study for baseline Space Station Program development:

- 1990 IOC for a manned Space Station in a 28.5° orbit
- 1993 IOC for a re-usable Orbital Transfer Vehicle (OTV)
- 1994 IOC for manned Space Station/Tended Platform in high inclination orbit
- Missions launched prior to Space Station IOC would be candidates for servicing/refurbishment, if practical

- All candidate Space Station payloads would be evaluated as to their suitability for mounting on the Space Station, either internally or externally.

A description of the Baseline Mission Model that resulted from the evaluation and screening process is contained in the following sections.

2.2 COMMERCIAL MISSIONS

The key ingredient in defining candidate commercial missions is to identify a marketable product that can return to the investor a net gain over the money invested in the Space Station, a return on investment (ROI).

Benefit analyses were performed for all candidate commercial missions to establish the potential for a ROI. The **commercial Baseline Model** included the commercial missions shown in Fig. 2.2-1 and the communication traffic to GEO summarized in Fig. 2.2-2.

The missions shown in Fig. 2.2-1 include:

- Communications - 4 missions
- Material Processing - 4 missions
- Earth Observation - 1 mission.

The Communications and Material Processing missions would be performed at 28.5° inclination. The Stereoscopic Imaging System requires a polar orbit for global coverage. Subsection 3.2 contains a detailed description of each of these missions including the benefit analyses.

The commercial communication traffic shown in Fig. 2.2-2 assumes that the Space Transportation System (STS), which includes the Space Shuttle plus a reusable OTV, would capture the following share of total communication satellite traffic:

- 45% of the International total
- 95% of the United States total
- 35% of the Foreign total.

The OTV becomes operational in 1993.

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ID NO.	MISSION	INCLINATION
GRUM-		
1000	COMMUNICATIONS R&D LAB	28.5°
1001	LAND MOBILE SATELLITE	28.5°
1002	INTERNATIONAL COMMUNICATIONS SATELLITE	28.5°
1003	HF BROADCAST SATELLITE	28.5°
1100	MATERIAL PROCESSING LAB	28.5°
1101	COMMERCIAL PRODUCTION OF HgCdTe	28.5°
1102	COMMERCIAL PRODUCTION OF BULK GaAs	28.5°
1103	COMMERCIAL PRODUCTION OF THIN FILM GaAs	28.5°
1104	COMMERCIAL PRODUCTION OF PROTEIN CRYSTALS	28.5°
1105	ISOENZYME SEPARATIONS	28.5°
1106	COMMERCIAL PRODUCTION OF BIOLOGICALS	28.5°
1107	X-RAY TARGET PRODUCTION	28.5°
1108	MONODISPERSE LATEX SPHERES	28.5°
1200	STEREOSCOPIC IMAGING SYSTEM	POLAR

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Fig. 2.2-1 Commercial Mission Summary

		EXPENDABLE PROPULSION			OTV OPERATIONS								
MASS, kg	USERS	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000	SUB TOTALS
700	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				2	2	2	2	3	2	1	0	14
	FOREIGN				1	2	0	2	1	1	1	0	8
	TOTAL				3	4	2	4	4	3	2	0	22
1000	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				0	1	1	1	1	0	0	0	4
	FOREIGN				0	1	1	1	1	1	0	1	6
	TOTAL				0	2	2	2	2	1	0	1	10
1500	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				4	6	6	3	0	3	2	1	25
	FOREIGN				2	1	1	1	1	0	1	0	7
	TOTAL				6	7	7	4	1	3	3	1	32
2300	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				2	3	0	2	2	1	2	2	14
	FOREIGN				0	0	1	0	0	0	1	0	2
	TOTAL				2	3	1	2	2	1	3	2	16
2800	INTERNATIONAL				1	1	1	1	1	0	1	0	6
	U.S.				0	0	0	0	0	0	0	0	0
	FOREIGN				0	0	0	0	0	0	0	0	0
	TOTAL				1	1	1	1	1	0	1	0	6
3100	U.S.				0	0	0	1	0	0	0	0	1
3800	INTERNATIONAL				0	0	0	0	0	2	2	2	6
10000	U.S. LAND MOBILE				0	0	0	0	0	2	1	0	3
5000	U.S. HF SOUND BROADCAST				0	0	2	0	0	0	0	0	2
	TOTALS FOR YEAR				12	17	15	14	10	12	12	6	98

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Fig. 2.2-2 Commercial Communications Traffic Using STS

A more complete discussion of the communication satellite traffic to GEO is contained in Subsection 3.2.1.5.

2.3 SCIENCE & APPLICATION MISSIONS

Development of the Baseline Mission Model for the Science and Applications Missions resulted in the following:

- All payloads requiring inclinations greater than 28.5° were placed in polar orbit
- About 85% of the orbit compatible payloads could be attached to a Space Station either internally or as an external mount
- A budget ceiling/constraint was applied to the Science and Application mission model
- Baseline Science and Application Mission Model included 48 missions as summarized in Fig. 2-2.

2.3.1 Polar Orbit Missions

When all the payloads that prefer either a polar orbit or approximately a 57° inclination orbit are summed, the total projected traffic cannot justify a permanent presence at more than one inclination. Since many payloads require polar orbit, all payloads requiring inclinations much greater than 28.5° were baselined as being in polar orbit. This subject is discussed in Section 2. All of the higher inclination payloads are shown in Subsection 2.3.4.

2.3.2 Space Station Attached Payloads

An evaluation was performed of all Space Station candidate mission/payloads to determine if the payload could perform its mission attached to a Space Station/platform either internally or as an external mount. The major considerations were:

- Compatible orbital parameters
- Space Station/platform environment (i.e., disturbances, contamination) would not nullify data gathering
- Ability to extend useful life of payload/instruments.

The results indicated that about 85% of the orbit compatible payloads (either 28.5° or polar) could be attached to a Space Station/platform either internally or as an external mount. The ability to attach payloads to a man-tended platform that provides pointing control, electrical power, data management, communications, and

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manned interaction reduces the cost of each individual mission/payload and, within the confines of a fixed total Science and Application budget, permits more science sooner.

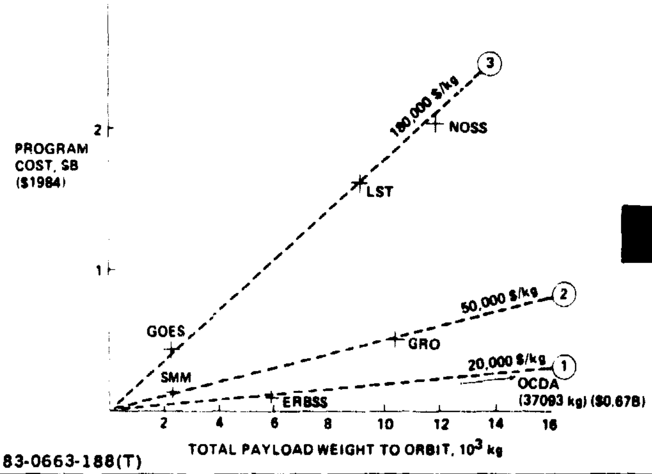
The mission/payloads that were baselined as attached to the Space Station/platform are shown in Subsection 2.3.4. More detailed descriptions are contained in Subsection 3.3.

2.3.3 Budget Analysis

An analysis was performed to consider the predicted total NASA budget projections for Science and Application missions in the 1990-2000 time-frame as a factor/constraint in defining the Baseline Mission Model.

Projected Program Costs (RDT&E plus production) and the on-orbit mass of a number of different classes of satellites were defined from informal NASA contacts and from in-house cost evaluation file data. The results are shown in Fig. 2.3-1. The data appeared to fall into three distinct bands of cost per unit mass.

High technology programs involving advanced state-of-the-art sensors and/or guidance and control formed one band at the upper left of Fig. 2.3-1, labelled No. 3. Data for the Geosynchronous Operational Environmental Satellite (GOES), Large Space Telescope (LST) and the National Oceanographic Satellite System (NOSS) fell into this category. A cost estimating relationship (CER) of $180,000 per kilogram appears to adequately represent this group.



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COST CER NO.	MISSION (GRUM-ID NO.)	WEIGHT (kg)	ESTIMATED COST ($M)
1	CHEMICAL REACTION STUDIES (0176)	1500	30
2	LARGE AREA MODULAR ARRAY (0204)	9416	471
3	RENEWABLE RESOURCES PLD (0227)	5400	972

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Fig. 2.3-1 Typical Satellite Program Costs vs Mass

A second band was based on high technology satellites not requiring major technology breakthroughs and is labelled No. 2 in the figure. Data on the Solar Maximum Mission (SMM) and the Gamma Ray Observatory (GRO) defined a slope of about $50,000 per kilogram.

A third type of satellite involving structural elements and more "conventional" technology hardware was found to be significantly less expensive per unit mass and formed a band in Fig. 2.3-1 labelled No. 1. Data for the Earth Radiation Budget Satellite (ERBS) and the Orbital Construction Demonstration article (OCDA) defined a CER of $20,000 per kilogram.

Based on projections of the NASA budget, it was estimated that the NASA Science and Application Budget for the 1990-2000 time-frame would average $1.08 billion per year, based on constant 1984 dollars, for an integrated allocation of $11.88 billion over the 11 year-period. Projected payload program costs (RDT&E plus production) were estimated using the data contained in Fig. 2.3-1. The total estimated cost of all Space Station candidate payloads is shown by the dotted line in Fig. 2.3-2. The budgetary constraint is shown by the solid line in the figure. As a result of this budgetary constraint, all payloads with projected IOC dates after 1997 were eliminated from the Baseline Mission Model. The IOC dates of the Baseline Model payloads were then adjusted to conform to the yearly budget ceiling. The results of this analysis are shown in Subsection 2.3.4.

2.3.4 Baseline Mission Model

The resulting Science and Application Baseline Mission Model is shown in the following figures:

- Astrophysics Mission - Fig. 2.3-3
- Solar Terrestrial Missions - Fig. 2.3-4
- Global Environment and Resource Observation Missions - Fig. 2.3-5
- Planetary Missions - Fig. 2.3-6
- Life Sciences and Material Processes Missions - Fig. 2.3-7.

Figures 2.3-3 through 2.3-7 contain the following information:

- The ID No. represents the payload element code on the Mission Data Sheets contained in Volume II, Book 1, Part IV
- The ID numbers provide the following information: 0100 series numbers are internal payloads; 0200 series numbers are externally mounted payloads; 0300 and 0400 series numbers represent free-flying satellites

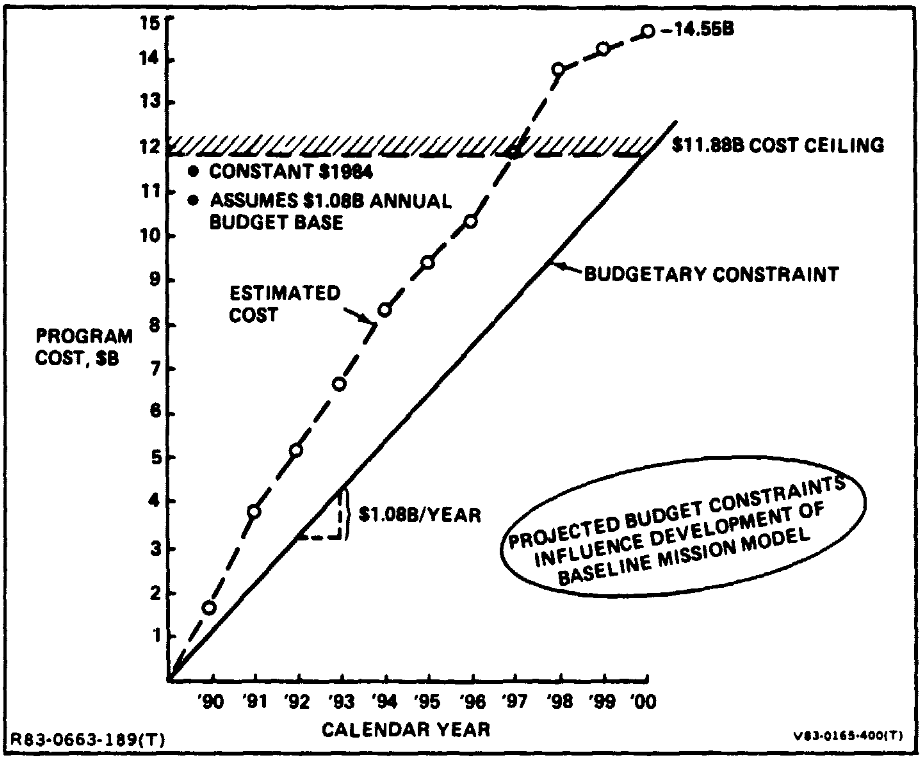

Fig. 2.3-2 Science & Application Budgetary Estimates

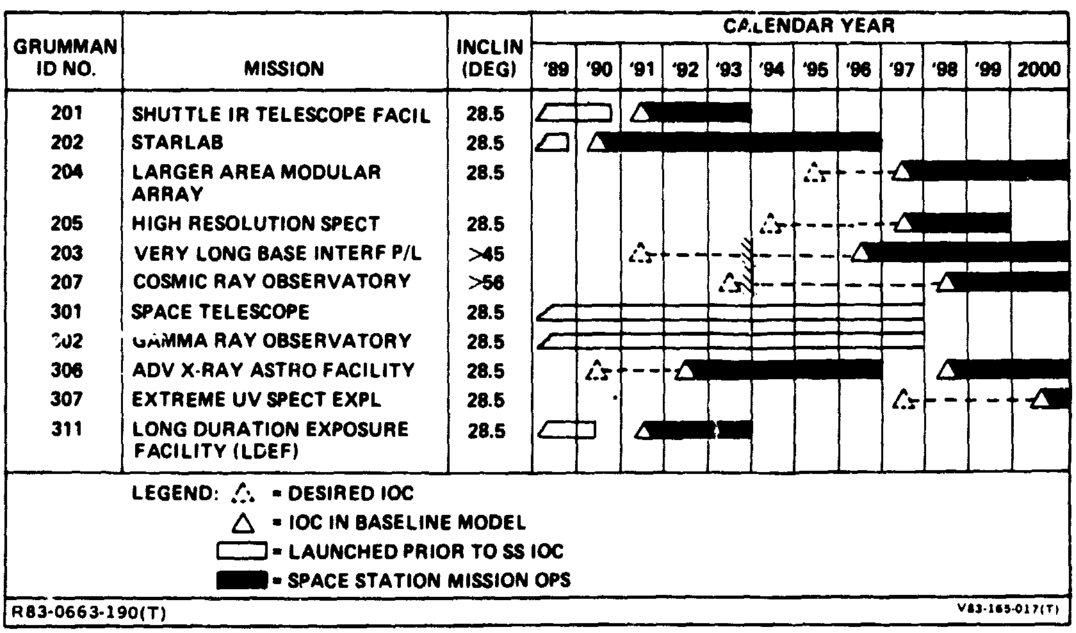

Fig. 2.3-3 Baseline Mission Model Astrophysics Missions

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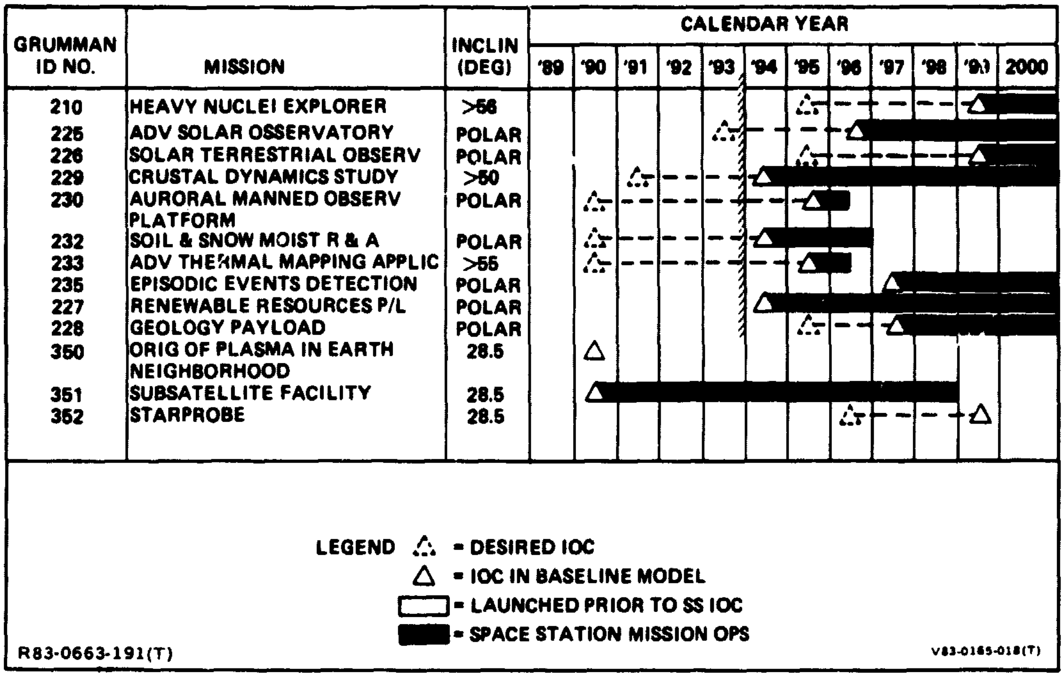

Fig. 2.3-4 Baseline Mission Model Solar Terrestrial Missions

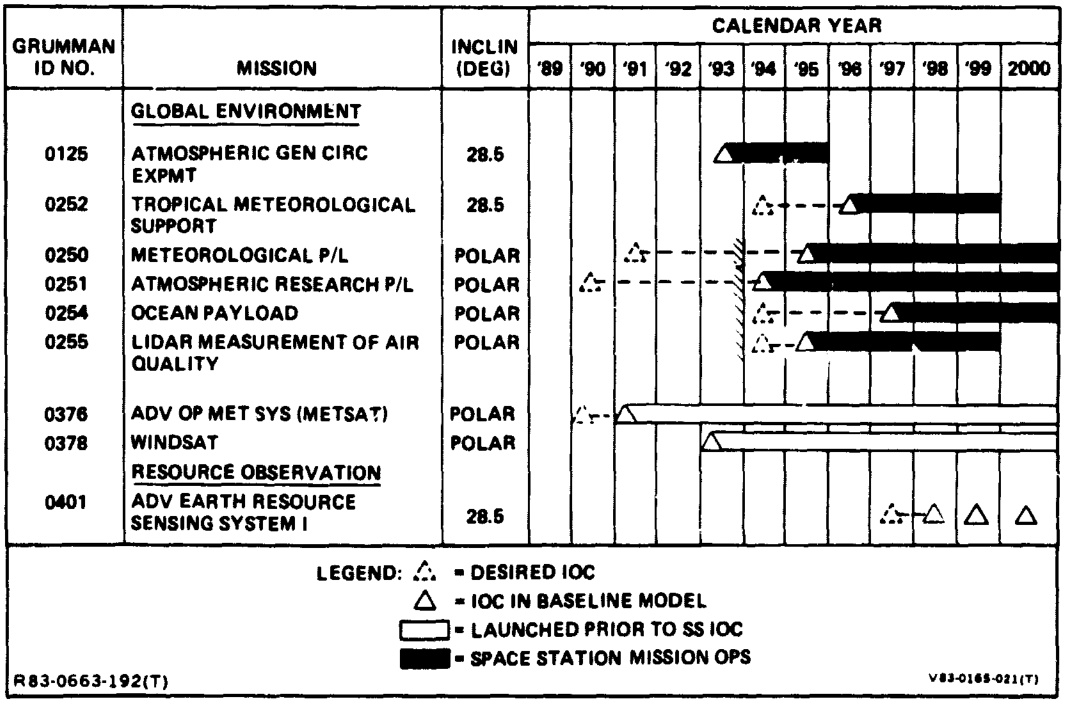

Fig. 2.3-5 Baseline Mission Model Global Environment & Resource Observation Missions

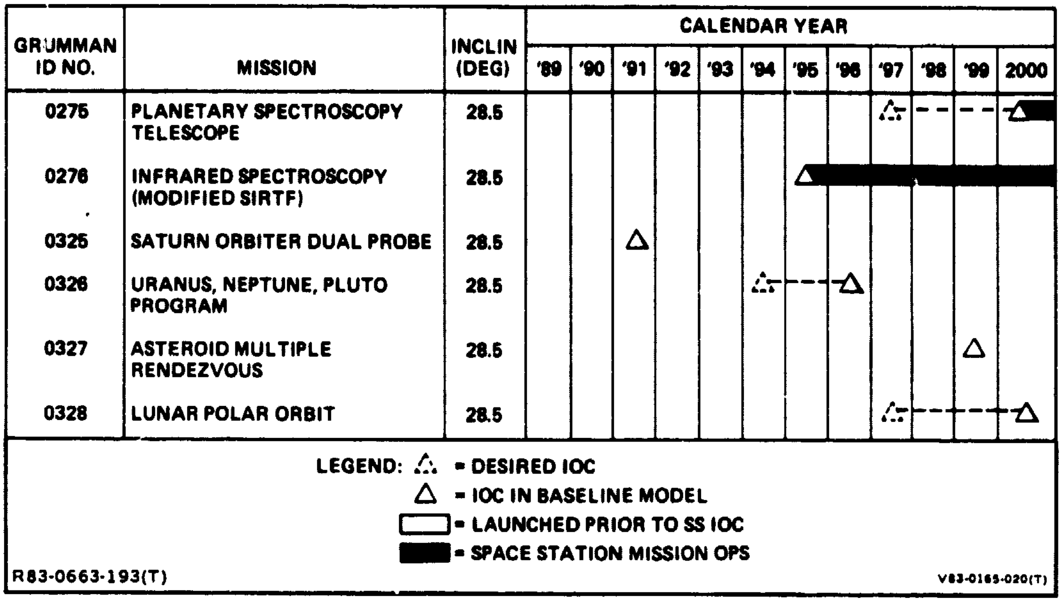

Fig. 2.3-6 Baseline Mission Model Planetary Missions

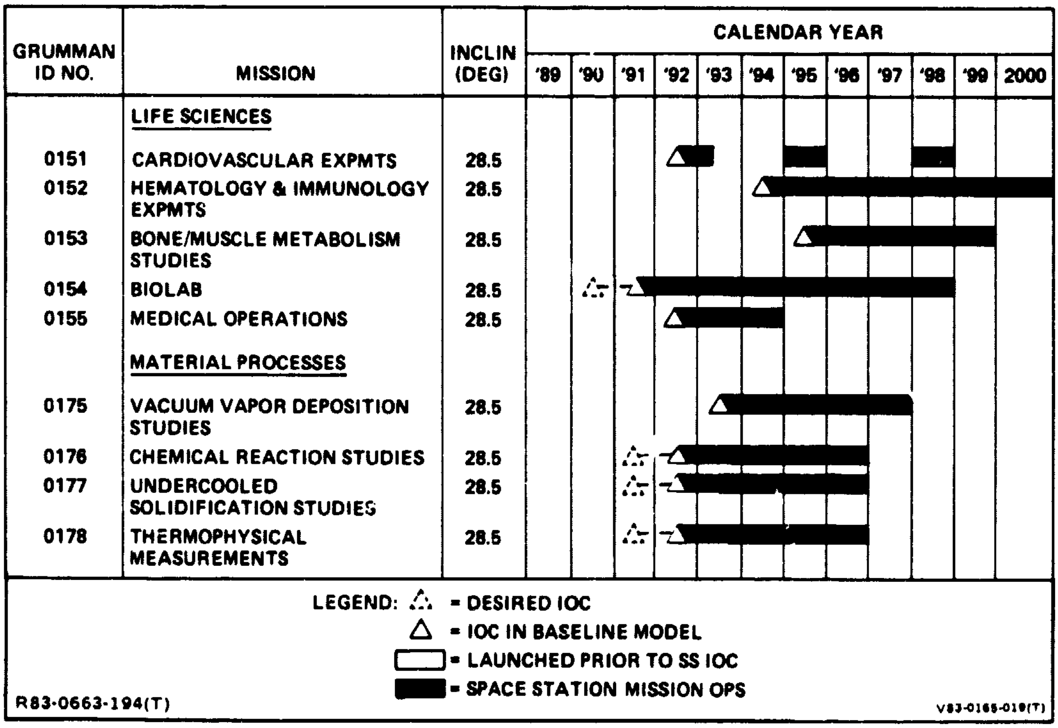

Fig. 2.3-7 Baseline Mission Model Life Sciences & Material Processes Missions

- The 'dashed' triangle represents the desired mission IOC data prior to application of the budget analyses/constraints described in Section 2.3.3
- The 'solid' triangle represents the resulting Baseline IOC date
- A 'solid' black bar following the triangle indicates Space Station mission operations. A solid bar following a 0300 series satellite (i.e., 0306) indicates that this satellite is serviced/refurbished via the Space Station. Servicing operations are described in Section 4
- An 'open' bar indicates that the satellite was launched prior to Space Station/platform IOC but is serviced via the Space Station during its operational life
- A triangle with no bar following it indicates a payload that could use the Space Station facilities for transport to its operational orbit/trajectory (space operations). Planetary mission payloads are examples in this category
- The recorded orbital inclinations represent the acceptable values for the particular mission. All payloads with inclinations greater than 28.5° were actually placed in polar orbit (refer to Subsection 2.3.1).

Figures 2.3-8 through 2.3-15 lists the 73 Science and Application missions that were evaluated and screened for applicability to the Baseline Mission Model. These figures contain the following information:

- Baseline IOC year for the 48 missions that form the Science and Application Baseline Mission Model
- IOC is listed as not applicable (NA) for those missions that were not included in the Baseline. Rationale is included for these missions. The comment, "Not included due to budget constraint," refers to the budget analysis described in Subsection 2.3.3.

All of the 73 missions listed in Fig. 2.3-8 through 2.3-15 are described in Subsection 3.3.

2.4 TECHNOLOGY DEVELOPMENT

The two Technology Development missions that were included in the Baseline Mission Model were:

- Communication R&D Lab (GRUM1000)
- Materials Processing Lab (GRUM1100).

SPACE STATION ASTROPHYSICS MISSIONS

ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM-	INTERNAL PAYLOAD		
0100	GEOLOGICAL PROCESS IN LOW GRAVITY	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
	EXTERNAL PAYLOADS		
0201	SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF)	1991	SHUTTLE PLD ADDED TO SPACE STATION
0202	STARLAB	1990	SHUTTLE PLD ADDED TO SPACE STATION
0203	VERY LONG BASE INTERFEROMETER PAYLOAD (VLBIP)	1996	
0204	LARGE AREA MODULAR ARRAY (LAMAR)	1997	
0205	HIGH RESOLUTION X-RAY & Y-RAY SPECTROMETER (HRS)	1997	
0206	GAMMA-RAY TRANSIENT EXPLORER (GTE)	NA	REPLACED BY NO.0205
0207	COSMIC RAY OBSERVATORY (CRO)	1998	
0208	X-RAY OBSERVATORY (XRO)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
0209	MULTICHANNEL ASTROMETRIC PHOTOMETER (MAP)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT

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Fig. 2.3-8 Baseline Mission Model Astrophysics Missions — Internal & External Payloads

SPACE STATION ASTROPHYSICS MISSIONS

ID NO.	PAYLOAD/MISSON	BASELINE MODEL IOC	RATIONALE/COMMENTS
	FREE FLYER MISSIONS		
0301	SPACE TELESCOPE (ST)	1995	LAUNCHED IN 1985, SERVICING ONLY
0302	GAMMA RAY OBSERVATORY (GRO)	1992	LAUNCHED IN 1987, SERVICING ONLY
0303	EXTREME ULTRAVIOLET EXPLORER (EUVE)	NA	LAUNCHED PRIOR TO SPACE STATION IOC
0304	X-RAY TIMING EXPLORER (XTE)	NA	LAUNCHED PRIOR TO SPACE STATION IOC
0305	GRAVITY PROBE B	NA	LAUNCHED TO POLAR ORBIT IN 1990
0306	ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)	1992	
0307	EXTREME UV SPECTROSCOPY EXPLORER (EUVSE)	2000	
0308	X-RAY SPECTROSCOPY (XSE)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
0309	SOFT X-RAY EXPLORER (SXE)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
0310	MOLECULAR LINE SURVEY (MLS)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
0311	LONG DURATION EXPOSURE FACILITY (LDEF)	1991	SHUTTLE PLD ADDED TO SPACE STATION
0312	ORBITING VERY LONG BASE INTERFEROMETER (OVLBI)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT

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Fig. 2.3-9 Baseline Mission Model Astrophysics Missions — Free Flyer Missions

ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM–	EXTERNALLY MOUNTED PAYLOADS		
0210	HEAVY NUCLEI EXPLORER (HNE)	1999	
0224	SOLAR OPTICAL TELESCOPE (SOT)	NA	LAUNCHED PRIOR TO SPACE STATION IOC
0225	ADVANCED SOLAR OBSERVATORY (ASO)	1996	
0226	SOLAR TERRESTRIAL OBSERVATORY (STO)	1999	
0227	RENEWABLE RESOURCES PAYLOAD (RRP)	1994	
0228	GEOLOGY PAYLOAD (GP)	1997	
0229	CRUSTAL DYNAMICS STUDY	1994	
0230	AURORAL MANNED OBSERVATION PLATFORM	1995	
0232	SOIL & SNOW MOISTURE RESEARCH & ASSESSMENT	1994	
0233	ADVANCED THERMAL MAPPING APPLICATIONS	1996	
0234	MULTIDISCIPLINE ADV. LAND OBS. SYS.	NA	SIMILAR TO RRP NO. 0227
0235	EPOSODIC EVENTS DETECTION (EED)	1997	
0236	ADVANCED EARTH RESOURCE SENSING SYSTEM	NA	MSLA INST. ADDED TO RRP NO. 0227
	FREE FLYER MISSIONS		
0350	ORIGIN OF PLASMA IN THE EARTH NEIGHBORHOOD (OPEN)	1990-93	FOUR SPACECRAFT LAUNCHED
0351	SUBSATELLITE FACILITY	1990	
0352	STARPROBE	1999	
0353	SOLAR INTERIOR DYNAMICS MISSION (SIDM)	NA	LAUNCHED PRIOR TO SPACE STATION IOC
0354	ADVANCED INTERPLANETARY EXPLORER (AIE)	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT
0355	SOLAR CORONA EXPLORER (SCE)	NA	LAUNCHED PRIOR TO SPACE STATION IOC

R83-0663-197(T) V83-0165-405(T)

Fig. 2.3-10 Baseline Mission Model Solar Terrestrial Missions

ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM–	INTERNAL PAYLOAD		
0125	ATMOSPHERIC GEN. CIRC. EXPERIMENT	1993	
	EXTERNALLY MOUNTED PAYLOADS		
0250	METEOROLOGICAL PAYLOAD	1995	
0251	ATMOSPHERIC RESEARCH PAYLOAD (ARP)	1994	
0252	TROPICAL METEROLOGICAL SUPPORT	1996	
0253	IMAGING RADAR EXPERIMENT (FIREX)	NA	INCLUDED IN OCEAN PAYLOAD NO. 0254
0254	OCEAN PAYLOAD	1997	
0255	LIDAR MEASUREMENT OF AIR QUALITY	1996	
	FREE FLYERS		
0374	LOWER ATMOSPHERE RESEARCH SAT (LARS)	NA	REPLACED BY ARP NO. 0251
0375	GEO. OPERATIONAL ENVIRONMENT SAT FOLLOW-ON	NA	REPLACED BY AERSS 1 NO. 0401
0376	ADV. OP. METEOROLOGICAL SYS. (METSAT)	1995	LAUNCHED TO POLAR ORBIT IN 1991, SERVICING ONLY
0377	OCEAN CIRC MISSION TOPOGRAPHY EXP (TOPEX)	NA	LAUNCHED TO HIGH INCL. ORBIT IN 1990
0378	WINDSAT	1997	LAUNCH TO POLAR ORBIT IN 1993 SERVICING ONLY
0379	UPPER ATMOSPHERE RESEARCH SAT (UARS)	NA	REPLACED BY ARP NO. 0251

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Fig. 2.3-11 Global Environment Missions

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ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM–	FREE FLYERS		
0400	ADVANCED LAND OBSERVING SYSTEM	NA	SAME AS AERSS NO. 0236
0401	ADVANCED EARTH RESOURCES SENSING SYS. I	1998-2000	FOUR SPACECRAFT LAUNCHED
040[illegible]	ADVANCED EARTH RESOURCES SENSING SYS. II	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT

R83-0663-199(T) V83-0163-403(T)

Fig. 2.3-12 Baseline Mission Model Resource Observation

ID NO.	PAYLOAD/MISSION	BASELINE	RATIONALE/COMMENTS
GRUM–	EXTERNALLY MOUNTED		
0275	PLANETARY SPECTROSCOPY TELESCOPE	2000	
0276	INFRARED SPECTROSCOPY (MODIFIED SIRTF)	1995	
	FREE FLYERS		
0325	SATURN ORBITER DUAL PROBE	1991	
0326	URANUS, NEPTUNE, PLUTO PROGRAM	1996	
0327	ASTEROID MULTIPLE RENDEZVOUS	1999	
0328	LUNAR POLAR ORBIT	2000	
0329	ORBITING IR SUBMILLIMETER TELESCOPE	NA	NOT INCLUDED DUE TO BUDGET CONSTRAINT

R83-0663-200(T) V83-0165-434(T)

Fig. 2.3-13 Baseline Mission Model Planetary Missions

ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM–	INTERNAL PAYLOADS		
0151	CARDIOVASCULAR EXPERIMENTS	1991	
0152	HEMATOLOGY & IMMUNOLOGY EXP.	1995	
0153	BONE/MUSCLE METABOLISM STUDIES	1994	
0154	BIOLAB	1991	
0155	MEDICAL OPERATIONS	1992	

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Fig. 2.3-14 Life Sciences

ID NO.	PAYLOAD/MISSION	BASELINE MODEL IOC	RATIONALE/COMMENTS
GRUM–	INTERNAL PAYLOADS		
0175	VACUUM VAPOR DEPOSITION STUDIES	1993	
0176	CHEMICAL REACTION STUDIES	1992	
0177	UNDERCOOLED SOLIDIFICATION STUDIES	1992	
0178	THERMOPHYSICAL MEASUREMENTS	1992	

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Fig. 2.3-15 Material Science

Both of these missions represent commercial R&D activities which have the potential for enhancing the marketability of commercial products in space.

The Communication R&D Lab mission is discussed in Subsection 3.2.1.1 and the Materials Processing Lab is described in Subsection 3.2.2.1.

Other potential Technology Development missions are discussed in Subsection 3.1.

2.5 FOREIGN MISSIONS

The foreign community will certainly support and indeed, actively participate in the U.S. Space Station Program. Many of the ongoing and projected foreign activities that would support/benefit from the Space Station Program are discussed in Subsection 3.5.

In general, the projected foreign missions for the 1990-2000 time-frame perform similar functions to the U.S. missions and therefore generate similar requirements. Consequently, the projected foreign missions were not formally considered as part of the Baseline Mission Model and were not a primary influence in establishing the mission-related requirements for the Space Station.

However, the projected foreign and international communication satellite traffic to GEO has been included in the Baseline Model and is summarized in Subsection 2.2.

2.6 MILITARY MISSIONS

The Baseline Mission Model includes the Military traffic to GEO, but not any other projected Military missions. The major purpose for treating most of the Military missions on an incremental basis was to provide both NASA and the Military with complete visibility as to the effect of the Military missions on the integrated mission-related requirements and subsequent Space Station architectural development.

The baseline Military traffic to GEO is summarized below.

YEAR	'93	'94	'95	'96	'97	'98	'99	'00
NO. OF SATELLITES	5	5	2	4	3	5	3	6

TOTAL = 33

A detailed discussion of all candidate Military missions and their effect on Space Station architectural development is contained in Volume II, Book 4.

A discussion of the integrated, civil plus military, mission-related requirements is contained in Section 5 of this volume.

3 - MISSION MODEL DEVELOPMENT

3.1 APPROACH

Grumman's approach to developing the Space Station mission model was to make maximum use of data currently available, then enhance these by adding and deleting missions as appropriate.

For the commercial missions, the combined resources of Grumman, General Electric and COMSAT General were utilized to develop a candidate list of missions/processes that were marketable and for which benefits analyses could be quantified.

For the Science and Application missions, the Space Operations Center (SOC) mission model was used to identify the candidate list of free-flying satellite missions. To this was added the sortie-type missions that required pressurized volume (internally mounted) and those that could be mounted externally on the Space Station structure.

The mission described in Section 3 were the candidates considered for the Space Station mission model. About 90 missions/payloads are discussed in this section. Of the 90 missions, 62 were selected for inclusion in the Space Station Baseline Mission Model. These 62 Baseline missions are identified in Section 2.

3.2 COMMERCIAL MISSIONS

Commercial missions are defined as those where a private (i.e., non-government) party buys or sells a product or service. In several cases the private sector may use a service, but unless the private sector directly pays for the service it is not a commercial mission. A prime example is a meteorological mission where the results are available to the public but not directly purchased and consequently non-commercial. The categories of commercial missions that are related to the Space Station are shown in Fig. 3.2.-1. In this figure the Space Station functions are identified as follows:

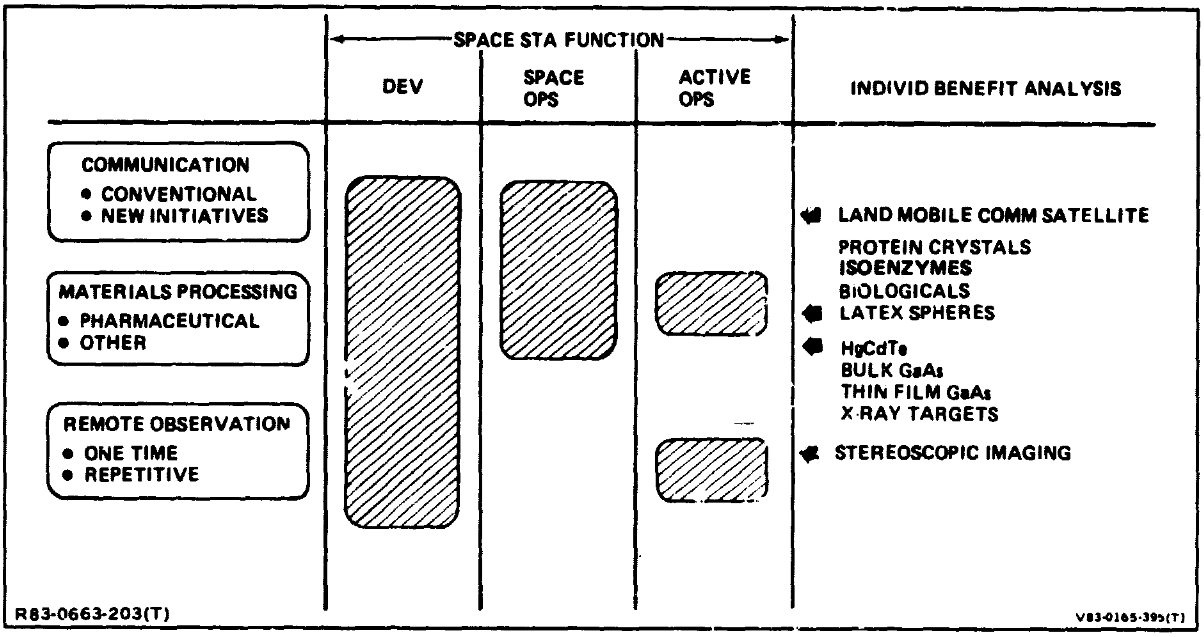

Fig. 3.2-1 Space Station Related Commercial Missions

- **Development** - Research and development facilities for new devices and products
- **Space Ops** - Support of deployments, transport, assembly, servicing, etc
- **Active Ops** - Facilities for on-board operations (e.g., loading a material processing furnace or control of free flyers).

The commercial mission must show a reasonable return on investment or a private party will not engage in the venture. The criteria for selection of commercial mission candidates in the 1990 decade involve:

- Introduction of a new or improved product or service by utilizing space
- Projected market value
- Estimated costs.

Selected missions must have a very high market value because space-related costs usually will be high relative to ground costs. For instance, the transport of materials to low earth orbit by the STS in the 90s is estimated to cost approximately \$2500/kg (\$83.3M each flight/34,000 kg). Assuming the total cost will be at least double the transport cost, and realizing the uncertainty of the projections in the 1990 time frame, the candidate product or service must sell for well more than \$5000/kg. A brief market analysis is required to ascertain the utility of space operations.

In addition to the above criteria for each mission, the incremental benefits of the Space Station must be assessed relative to potential alternatives. All of the missions presented in this subsection benefit by using a Space Station, but in varying degrees. The benefits have been quantified by relative costs for the missions indicated in Fig. 3.2-1. The relative costs were determined using simplified calculations which are included in each mission subsection. The simplified procedures, although subjective and not completely detailed, are believed commensurate with the scope of the study. The Space Station program costs have been excluded from the cost comparisons for each mission. The Space Station costs are compared to the accrued benefits from all the selected missions; this information is presented later in Volume II - Book 3. The STS costs play a major role in all benefits analyses. The STS groundrules used, plus other groundrules, are given in Fig. 3.2-2.

SHUTTLE

- PRACTICAL REVISIT INTERVAL TO A FREE FLYER IS 60 DAYS OR MORE
- PRACTICAL REVISIT INTERVAL TO THE SPACE STATION IS 30 DAYS
- ALL COSTS ARE IN 1984 DOLLARS
- DEDICATED FLIGHT COSTS $84.3M
- NOMINAL CHARGE IS $3306/kg (0.75 OF 34,000 kg MAX LOAD)
- MINIMUM CHARGE IS $6M FOR LOADS UP TO 1700 kg
- NO CHARGE FOR RETURN OF PAYLOADS TO GROUND FROM SPACE STATION
- RENDEZVOUS CHARGE IS $0.88M
- MAX PRACTICAL ORBITER STAY IS 7 DAYS, CHARGE IS $.66M/DAY AFTER 1ST DAY

OTHER

- LABOR CHARGE ON SPACE STATION IS $3400/MAN-HR
- GROUND LABOR CHARGE IS $1500/MAN-HR
- SPACELAB CHARGE IS $10M PER FLIGHT
- MAX FREE FLYER RESUPPLY INTERVAL IS 6 MONTHS
- ACQUISITION COSTS (PROCURING FOUR)
  - 5 kW FREE FLYER ~ $180M
  - 22 kW INDUSTRIAL PLATFORM – $450M

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Fig. 3.2-2 Groundrules for Benefit Analysis

The significant time-phased requirements relating to Space Station architecture and traffic analysis are given in this subsection for each mission. These requirements are derived from the estimated annual deployments of equipment and the annual production of each mission product. Other requirements are given in the Payload Element Mission Data Sheets, Part IV of this volume.

It must be realized that the missions and benefits all represent projections 10 to 20 years in the future. Most of them are dependent on R&D that presumably will be accomplished in the 1980s. Some missions presented might not remain viable but others not yet thought of probably will replace them.

The missions selected for the Space Station represent the efforts of Grumman, General Electric and COMSAT General. The missions and the responsible team members are listed in Fig. 3.2-3.

MISSIONS	GRUMMAN	G.E.	COMSAT
COMMUNICATIONS			
RESEARCH & DEVELOPMENT			√
LAND MOBILE SATELLITE			√
INTERNATIONAL SATELLITES – DEPLOY & SERVICE			√
HF SOUND BROADCAST SATELLITE			√
MATERIALS PROCESSING			
RESEARCH & DEVELOPMENT	√		
PRODUCTION OF HgCdTe	√		
PRODUCTION OF BULK GaAs	√		
PRODUCTION OF THIN FILM GaAs	√		
PRODUCTION OF PROTEIN CRYSTALS	√		
ISOENZYME SEPARATIONS		√	
PRODUCTION OF BIOLOGICALS		√	
X-RAY TARGET PRODUCTION		√	
PRODUCTION OF LATEX SPHERES		√	
EARTH OBSERVATIONS			
STEREOSCOPIC IMAGING SYSTEM		√	

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Fig. 3.2-3 Selected Commercial Missions & Responsible Team Members

3.2.1 Communications Missions

Communications satellite missions that would potentially benefit from the use of a Space Station are described in this Subsection 3.2.1, which was prepared by COMSAT General Corporation.

A major activity was the development of a forecast of future satellite trends and benefits that could be derived from the use of specific Space Station capabilities.

Since all telecommunications spacecraft operate at geostationary orbit, one might conclude that a low-orbit Space Station is not useful for commercial satellites. A technically cautious industry could reach this conclusion despite promises of satellite low earth orbit testing before commitment to GEO orbit, orbital testing of large antennas, orbital assembly of satellites with orbital transfer vehicles, etc.

In order to assess realistically the importance of manned Space Stations, COMSAT General prepared a document containing a forecast of satellite traffic and relevant technology trends to the year 2000. Also included were those Space Station capabilities and characteristics that should be provided to make the station useful to commercial satellite owners. The document was circulated to key representative organizations within the commercial telecommunications satellite and related communities of interest, including spacecraft manufacturers, commercial satellite owners, communications carriers, networks and risk insurers.

Our purpose in developing this prospectus was to:

- Provide NASA with a forecast of future commercial satellites and those Space Station capabilities that would be beneficial to U.S. commercial satellite builders, owners and the public that uses the services provided
- Provide COMSAT General's views of the circumstances under which those capabilities are likely to be used
- Obtain an endorsement from the commercial telecommunications community of the prospectus as written or identify points of major disagreement.

Volume II - Book I, Part III of this volume contains the following:

- The COMSAT prospectus document
- A copy of the transmittal letter and the mailing list of key companies involved in commercial telecommunications activities that were contacted
- A summary of industry comments as well as copies of the individual responses.

A summary of the significant industry comments appears in the following paragraph.

The prospectus was sent to 42 organizations (including 15 representing the insurance industry). Replies were received from 22 of the organizations as of March 10, 1983 (it is significant that the response percentage was over 50%). The general consensus of the responses was an overall endorsement of the future satellite projections and possible uses and benefits that would be derived from the existence of a Space Station.

The following is a summary of potential benefits that were developed in the prospectus document:

1) A low earth orbit U.S. Space Station program may have a major effect on future satellite orbital operations, orbit-to-orbit transportation, and eventually the configurations of future specialized telecommunications satellites. While the Space Station capabilities described earlier are not required to meet commercial communications needs currently anticipated through the late 1990s, the ultimate benefits could be significant. It is therefore believed that the wide range of operational services that will be developed as part of the U.S. Space Station program will ultimately have favorable impact on communications satellite configurations, capabilities and costs, to the benefit of the commercial sector. The commercial sector should maintain an awareness of and an involvement in the determination of orbital services that will be developed.
2) Assessment of benefits and future uses is influenced to a large degree by the costs of Space Station services to the commercial sector, such as in-space assembly, repair, checkout and launch. NASA must define such economic philosophies and pricing structures.
3) There must be demonstrations of orbital services and cost benefits before the characteristically conservative commercial communications industry will commit to their operational use.
4) Until transportation and service cost benefits are demonstrated, the low earth orbit Space Station is likely to be used mainly as an R&D test facility.
5) By the late 1990s, the benefits available from satellite servicing, in-space assembly, repair and checkout and satellite fueling could allow much greater flexibility to the industry in developing new communications satellite configurations, architectures and services.

It is clear both in the prospectus and in several of the industry comments that Space Station services must be cost-competitive with current practices to be attractive, and must be demonstrated by NASA to be credible.

The following subsections describe four communications missions which are particularly attractive candidates for commercial use.

Space Station usefulness to the communications satellite industry up to the year 2000 should be mainly for:

- Space communications system research and development
- Reliability enhancement by providing for spacecraft checkout and deployment in LEO before commitment to GEO
- LEO integration and test of future very large land mobile communications spacecraft
- LEO integration and test of future very large international HF sound broadcast satellites.

While the apparent value of a Space Station in these activities is covered in the following subsections, specific commercial enterprises have not been postulated.

Some mission categories are very cost-sensitive because the use of the Space Station must compete with the current methods of accomplishment. For other mission categories, the Space Station enables missions to be accomplished that are not practical with current facilities.

3.2.1.1 **Communications Research & Development** - The commercial satellite communications industry has not funded a significant level of spaceborne experiments because of the costs. The consequence has been that commercial spacecraft have been conservatively designed with cautious introduction of new technology, particularly where it cannot be adequately proven in ground test. The advent of the Space Station can provide a lower cost space facility for conducting space experiments. The type and number of the experiments the commercial sector would fund will depend on the cost of the experimental hardware as well as Space Station charges. With the assumption that these charges are reasonable in terms of benefits, several candidate experiments can be currently identified for the Space Station. They are summarized in Fig. 3.2-4.

	MASS, kg	VOLUME	POWER, kW	DURATION
LARGE ANTENNA STRUCTURAL TESTING	1800	55 m dia	.50	2 WEEKS
INTERSATELLITE LINK PLUS CO–ORBITING SPACECRAFT TO TRANSMIT & RECEIVE	100	1 m^3	.10	1 MONTH
IN ORBIT SERVICING DEMONSTRATION	500	8 m^3	1.50	1 YEAR
THRUSTER PLUME IMPINGEMENT	100	2 m^3	.10	7 DAYS
FLUID DYNAMICS	500	8 m^3	.20	2 DAYS
ION THRUSTER	100	1 m^3	.80	1 YEAR
MAGNETIC MOMENTUM WHEEL	50	1 m^3	.20	1 DAY

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Fig. 3.2-4 Commercial Communications Lab Experiments

These candidate experiments would provide data useful to the commercial sector that would hasten the use of new technology in operational programs or reduce risk where technical uncertainties exist. They would rely on Space Station services such as power, data handling and collecting of material samples. The experimental modules are envisioned as one experiment per module and operated remotely. Thev would be extracted from the shuttle bay and attached to a Space Station attach fitting with the necessary services. They would typically require crew involvement in their setup and operations. The ability to return the experiments to earth for refurbishment is expected to help reduce costs. Some candidate experiments are described in the following paragraphs.

Large Reflector Structural Testing - Certain potentially profitable communication missions require very large antennas (reflectors or phased arrays) (50 to 300 m) that have critical contour accuracy requirements that are not sufficiently determined during ground test. This experiment would demonstrate contour accuracy and performance of adaptive surface control if required in the thermal environment. The stowed antenna would be mounted to a support structure, the antenna deployed and contour measurements made under a variety of sun angles. The antenna might then be modified to improve performance while at the Space Station or even returned to the ground for more extensive rework and subsequent retest in orbit. This type of testing is considered a prerequisite before commercial satellite owners would commit to the use of large antennas. Figure 3.2-5 shows such an experiment.

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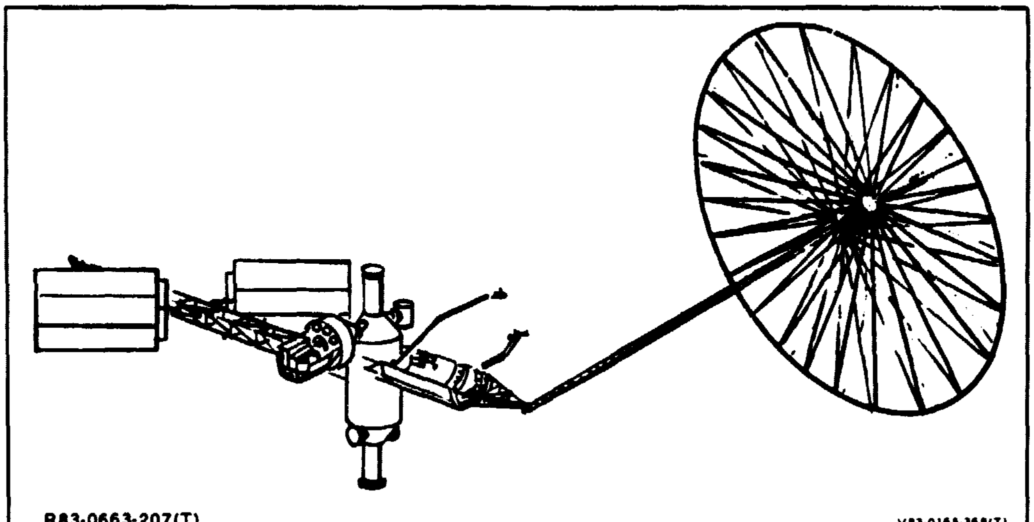

Fig. 3.2-5 Research & Development on Large Antenna Structure

Intersatellite Link Demonstration - Future system studies have shown that an intersatellite link (ISL) can enhance network efficiency. This experiment would demonstrate the communications performance of such a link in the space environment at various frequencies. The experiment would require a spacecraft to co-orbit with the Space Station so that a link could be established with the Station-mounted ISL equipment.

Spacecraft Remote Servicing Demonstration & Technology Development - There are economic advantages to extending the life of communications satellites by servicing in GEO. No commercial user is likely to commit to a serviceable spacecraft until the technology and capability is well developed. The Space Station can support the experiment necessary to develop key technologies. A simple model of the GEO servicer free flyer can be used with a simulated spacecraft attached to the Space Station to demonstrate key servicer functions. The station also can support the servicing and resupply of the free flyer itself.

Thruster Plume Impingement - When thruster exhaust plumes impinge upon surfaces, forces are produced, heating occurs and constituents of the plume may be deposited. There are analytical techniques for predicting these effects but with an increasing degree of uncertainty for force, heating and deposition predictions. Experimental substantiation on the ground is extremely difficult because of the need for very low back pressures and large volumes for the test chambers.

The space experiment includes surfaces that would be located around the thruster being evaluated. Different test surfaces would be used for force measurement, heat transfer rate measurements and for retention of deposited materials. When the thruster fires, the forces would be measured immediately and the heat transfer could be measured within a few minutes, but collection of deposit could require days.

The placement of the test plates would require a fixture or movable arm.

Data collection for the force and heat transfer measurements would be simple (that is, recording transducer outputs). Since these data are not time-critical, they could be transmitted back to the ground whenever convenient.

The material deposited from the plume will vary with the temperature of the surface so thermal control may be necessary. In some cases only the mass values are needed; in others, the composition of the deposit is also of great interest. The chemical analysis might be done instrumentally, but physical collection of material samples might also be necessary. Collection would require more complex apparatus and handling, or possibly an EVA.

Fluid Dynamics - Liquid motions in spacecraft can cause disturbance forces that must be counteracted by attitude control systems. Some of these forces are difficult to predict. Nutation build-up on spinning spacecraft is a prime example. Measurements on the ground can be difficult and expensive, but also can be perturbed by gravity. Models of propellant tanks could be spun up near a Space Station on a free flying platform, and the nutation growth observed. The moment of inertia ratio of the platform and the liquid fill fraction of the tanks would be varied and the nutation build-up time constant measured. The varying of the parameters would probably require crew activity.

Ion Thruster - Electric propulsion offers the chance to reduce propellant mass requirements for many spacecraft missions. The thrust is low so long firing times are required. The preferred concept, that of ion thrusters, has been under development for a few decades and has a reasonable maturity. However, life testing is always difficult. Very low pressures and large volumes are required to avoid back scattering. Additionally, gravity causes settling of particles, which is different from the space condition.

The installation of an ion thruster should be rather straightforward, though the direction must be selected to avoid disturbance to the Space Station orbit. The ion beam must also be avoided. Sputtered material must be kept off critical surfaces. This is likely to require shielding, which can also be used for contamination measurements.

Magnetic Bearing Momentum Wheel - The performance of a magnetically suspended rotor in zero gravity is not well understood. The experiment would consist of measuring rotor dynamics with disturbance torques imposed.

3.2.1.2 Land Mobile Satellite - Some candidate experiments in the Land Mobile Satellite area are described in the following paragraphs.

Market Analysis - Land Mobile Satellite Service in the 806- to 890-MHz band is an augmentation to the terrestrial cellular mobile radio services to be implemented in many urban areas of the continental U.S. in the next few years. Users in rural areas and on interstate highways, using the same vehicular equipment, would be served via satellite relay to fixed earth stations tied into the nation's cellular mobile and telephone networks.

A possible evolution of land mobile communications satellite system is shown in Fig. 3.2-6. Note that in estimating annual revenue potential for each system, it is necessary to assume that rapid expansion in the number of users served is accompanied by a pattern of sharply declining prices for service.

YEAR OF FIRST LAUNCH	MODEL	NUMBER OF SATELLITES ACTIVE/SPARE	SYSTEM FREQUENCY REUSES	ANTENNA DIAMETER (m)	LEO STAGING	NO. OF SYSTEM USERS	ANNUAL REVENUE POTENTIAL $'84 M	BOL SPACECRAFT MASS, kg
1989	I	2/1	8	32	NO	176,000	200	2,000
1994	II	2/1	26	55	NO	500,000	400	4,000
1998	III	2/1	64	91	YES	1,400,000	700	10,000

NOTE: TABLE ASSUMES ONLY 20 MHz FCC ALLOCATION IN 806 TO 890 MHz ITU BAND. MORE SPECTRUM MEANS SMALLER SATELLITES. FOR HIGH DEMAND SERVICES, FCC SPECTRUM ALLOTMENTS CAN BE INCREASED THROUGH TECHNICAL/POLITICAL PROCESS.

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Fig. 3.2-6 Possible Evolution of Land Mobile Communications Satellite System (Conus Service)

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Mission Description - The satellites would employ large antennas in geostationary orbits to provide nationwide coverage comprising about 100 hexagonal cells, each about 200 miles wide, as shown in Fig. 3.2-7. This type of coverage can only be provided from space, because propagation between vehicles and base stations on the ground is restricted by terrain to distances of only a few miles. Thus, a ground-only system would require so many base stations that the cost would be prohibitive.

An initial version of the land mobile satellite might employ a moderate-sized antenna to provide nationwide service using a few very large (800-mile) cells. However, the number of users who can be served in a given cell is severely limited by the radio-frequency spectrum, which can only support about 100 simultaneous voice channels within a given cell. Therefore, later versions of the satellite would be forced to employ larger antennas, capable of producing greater numbers of smaller cells, in order to serve a growing user constituency. The relationship between antenna diameter and cell diameter (and total number of spectrum reuses) is shown in Fig. 3.2-7. The number of spectrum reuses equals one-sevenths the number of cells, since each cell can be allocated only one-seventh of the total spectrum to permit it to be surrounded by six cells using the remaining six-sevenths of the spectrum.

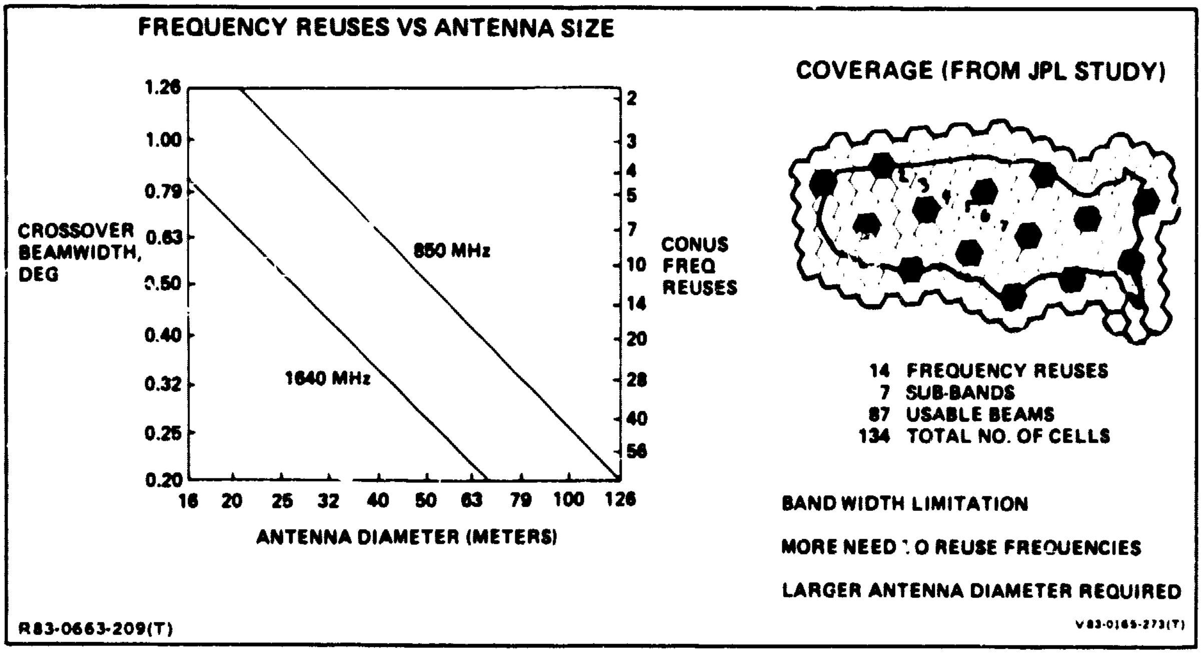

Fig. 3.2-7 Frequency Reuse Related to Antenna Size for Land Mobile Satellite System

The mature land mobile satellite shown in Fig. 3.2-8 was investigated by JPL (Reference 1) and is expected to employ antenna diameters of 50 to 100 m. Such spacecraft can be deployed and tested in LEO and mated with an orbit transfer vehicle for a soft ascent to GEO.

Requirements - The potential role of the Space Station in support of communications satellites in the time frame beyond 1990 is envisioned as reliability and availability enhancement. A crucial contribution would be aiding the deployment of very large complex spacecraft that would represent unreasonable risks without the support of the station.

As communications spacecraft grow larger and more complex, with resultant increase in investment per unit, the consequences of failure also grows. Communications spacecraft are characterized by many deployments to develop the complex antenna farm that typifies them. The risk of deployment failure overhangs every program. The possible loss of a $100M spacecraft from a deployment failure should make the commercial community receptive to a role for the Space Station if reliability can be improved. The sequence envisioned in the deployment of a Land Mobile Service spacecraft utilizes the station as a staging area before raising the spacecraft to GEO. The sequence is broadly applicable to other communications missions

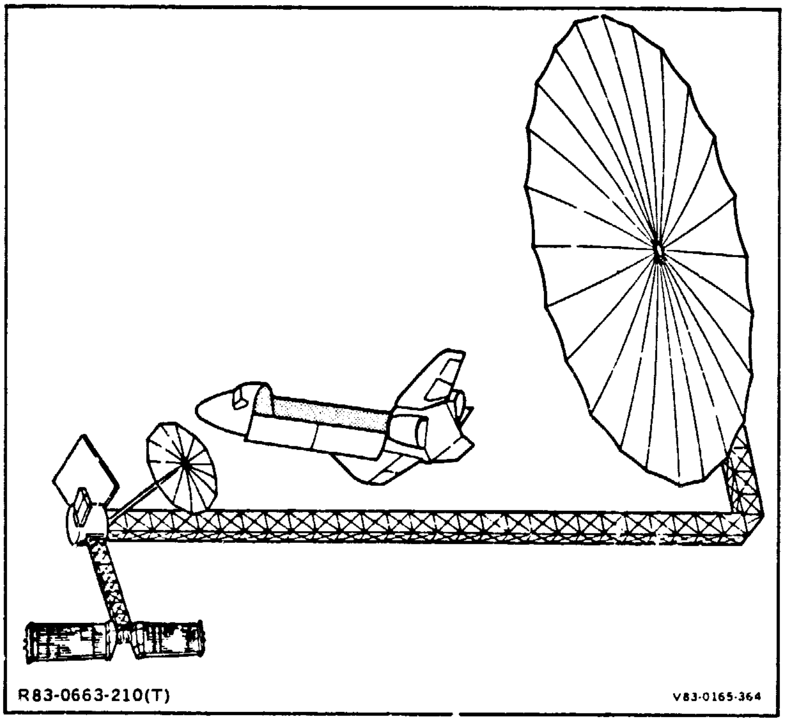

Fig. 3.2-8 Land Mobile Satellite – 55 m Antenna

(e.g., Intelsat, HF Broadcasting, etc). The steps are as follows:

- Shuttle launch to Space Station orbit
- Extract spacecraft from shuttle and attach to Space Station. Connect power and command buses of Space Station to spacecraft
- Initial health and status checkout of spacecraft. Space Station serves as data and command conduit to the spacecraft's terrestrial control center for all in-orbit testing
- Extend deployable structural elements of spacecraft
- Repair spacecraft as required. Bring up spare equipment if needed on next shuttle flight. EVA may be required for certain service functions
- Undock spacecraft. Spacecraft moved some distance to co-orbit with Station
- Station collects and retransmits antenna pattern data as free flying spacecraft sweeps Space Station
- Spacecraft returns to Space Station for integration with OTV
- OTV raises spacecraft to apogee at GEO altitude
- Spacecraft integral propulsion circularizes orbit at GEO altitude.

The major steps are illustrated in Fig. 3.2-9 using an International Communications Satellite as an example. The availability of a Space Station, within the con-

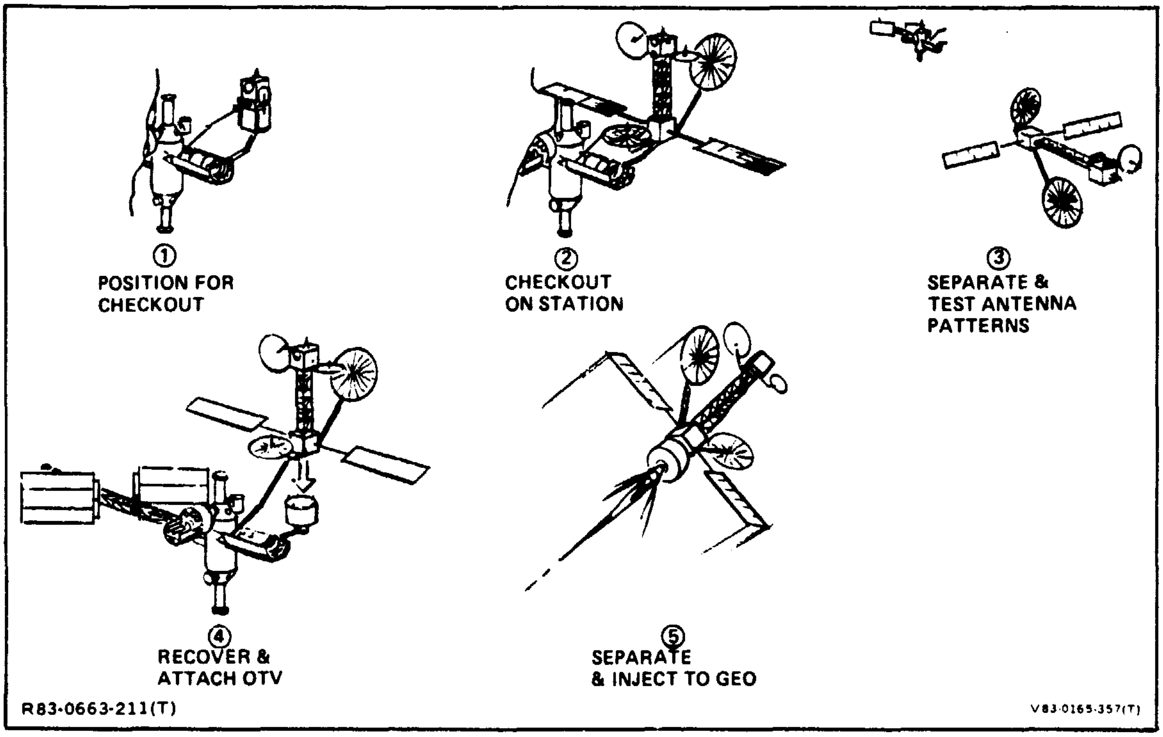

Fig. 3.2-9 International Communications Satellite Deployment

text of LEO testing of spacecraft destined for GEO, provides an easy method of performing large-antenna far-field pattern measurements. The spacecraft is tested while docked, then detached and deployed as a co-orbiting free flyer about 10 miles from the Space Station.

To characterize the land mobile satellite with the coverage pattern shown in Fig. 3.2-7, 100 to 200 rotational cuts would be needed. At one cut per revolution and 0.1 rpm, this would require 17 to 33 hours of data taking. But a favorable geometry for data taking only occurs twice per orbit, so that the number of cuts per orbit might be reduced to two or four. Thus, the time needed to accumulate all the data could extend to 100 orbits, or about one week. Additional time would be needed for preparatory and post-test maneuvering.

The spacecraft would have to be procured and designed with the expectation of using these or similar procedures in LEO. New design requirements could include provision for in-orbit equipment replacement, astronaut safety and retractable structures so spacecraft could be returned to earth for repairs that might not be possible in orbit. Communications spacecraft typically have a high degree of component redundancy so that not all failures would require repair, only those that reduce reliability or performance below an acceptable level.

The spacecraft would have to be capable of docking with the station and OTV. Additionally it must function as a free flyer in LEO which implies adaptations to its control system.

The significant time-phased requirements for deployment and testing of the satellite are given in the schedule, Fig. 3.2-10. Other requirements are given in the Payload Element Data Sheets, Part IV of this volume. The satellite mass of 10,000 kg includes an integral propulsion system for circularization at GEO altitude.

Benefit Analysis - The land mobile satellite foreseen in this century is not likely to be large enough to require a Space Station for deployment. However, analysis indicates that cost savings would be possible with a station available. Two methods of qualifying and placing an operational system in space were studied. The two alternatives follow.

	'97	'98	'99	2000
SATELLITES TRANSPORTED	–	2	1	–
SATELLITE MASS TRANSPORTED, kg	–	20,000	10,000	–
SATELLITES OPERATING/SPARE	–	2	2/1	2/1
MATERIALS TRANSPORTED, kg	–	–	–	–
CREW TIME* man-hr	–	960	480	–
OPERATING POWER, kW	–	1.0	0.5	–
POWER DUTY CYCLE	–	0.2	0.2	–
LENGTH FOR STS, m	–	18	18	–

* 8 MAN-HR PER DAY EACH SATELLITE

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Fig. 3.2-10 Schedule for Land Mobile Satellite

The use of a Shuttle/Centaur is on the order of $300M more expensive than the Space Station with reusable OTV. This evaluation is a consequence of a three-satellite mission scenario in the late 1990s involving qualification and acceptance tests of the very large antenna in LEO. The calculation of the comparative costs for one mission are shown in Fig. 3.2-11. Without the Space Station, the land mobile system requires one additional shuttle flight for ground repair and return to

	SHUTTLE + CENTAUR G	$M	SPACE STATION + OTV	$M
LAUNCH TO LEO				
SATTELITE	2 FLTS, DEDICATED BY LENGTH	168.6	1 FLT, DEDICATED BY LENGTH	84.3
TRANSFER VEHICLE/PROP.	17040 + 3950 kg (0.83CF)	70.0	31,000 kg, PROPEL + TANK	84.3
RENDEZVOUS @ $0.88M	1 WITH SATELLITE	0.9	2 WITH STATION	1.8
TEST, ASSEMBLY & CHECKOUT				
ORBITER LOITER @ $0.66M/DAY	18 DAYS	11.9		
SPECIAL FIXTURES				10.0
LABOR @ $0.034M/MAN-DAY	INCLUDED IN LOITER CHARGE		18 DAYS x 2 MEN x $0.034M	1.2
MODIFICATION				
TRANSPORT REPLACEMENT PARTS	DONE ON GROUND	NEG.	MINIMUM LAUNCH CHARGE	6.0
LABOR @ $0.034M/MAN-DAY	DONE ON GROUND	NEG.	30 DAYS x 2 MEN x $0.034M	2.0
TRANSFER TO GEO				
TRANSFER VEHICLE COST/FLT	4/YEAR PROCUREMENT	38.0	OPERATIONS	10.6
COMPARATIVE TOTAL		289.4		200.2

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Fig. 3.2-11 Comparative Costs of Deploying One 10,000 kg Land Mobile Satellite

LEO. In addition, the use of an OTV with the Space Station provides additional economies over the Centaur.

3.2.1.3 International Communications Satellite-Deployment & Servicing - The following paragraphs describe implications affecting experiments in this area.

Market Analysis - Intelsat VI is currently under development. Five spacecraft will be delivered, with the first launch expected in 1986. Traffic growth projections shown in Fig. 3.2-12 suggest the international system will require the first launch of an Intelsat VII in 1992. The procurement cycle leading to the contract would have to begin in 1987, at the latest, to meet the launch date. This precedes Space Station availability; thus, the spacecraft design requirements would not be adapted to anticipate a mandatory role for a Space Station in its launch and deployment to GEO.

Continued traffic growth indicates a need for a new spacecraft design, Intelsat VIII, in 1998. This spacecraft procurement could require the support of a Space

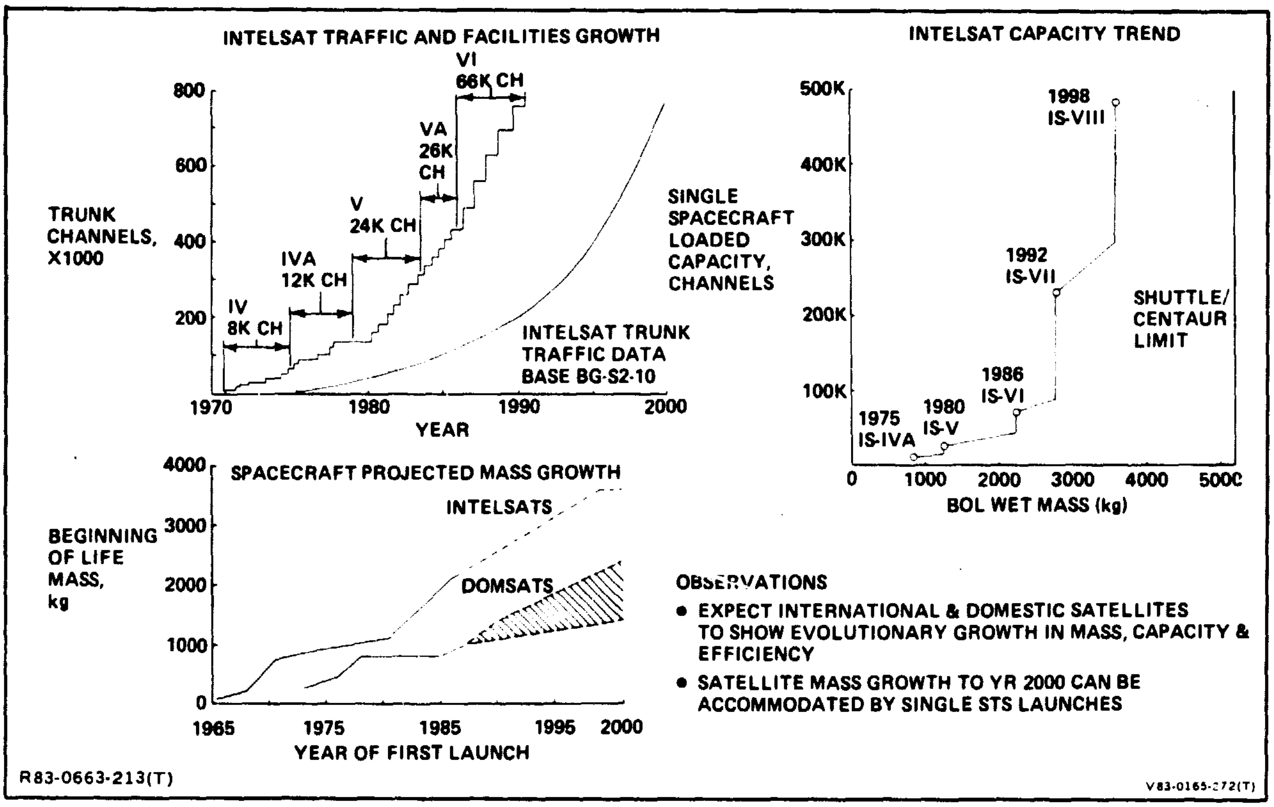

Fig. 3.2-12 Satellite Traffic, Capacity & Mass Projections

Station if the cost and/or reliability benefits have become obvious to Intelsat. The spacecraft at 3800 kg can be launched conventionally; a station is not required as it would be for some other communications missions.

Mission Description - The projected growth in the international communications arena is shown in Fig. 3.2-12. The estimate shows the introduction of Intelsat VIII in 1998. This spacecraft could be a good candidate for operating with the Space Station. The spacecraft deployment to GEO could be conducted as described for the Land Mobile Satellite. The station could, in addition, assist in the remote servicing of the international satellite network in GEO.

Studies (References 2 and 3) have considered several methods of servicing GEO spacecraft. The most viable scenarios consist of a service vehicle that could be docked at the Space Station and go to GEO when service is required, and then return to LEO; or, as an alternative, the service vehicle could dwell in GEO until service is needed. In either case the plan calls for the service vehicle to sequentially visit the satellites on a routine service schedule.

Routine servicing could be performed, perhaps every five years, with fueling and equipment module replacement. The remote servicer dwelling in GEO would, itself, require resupply of fuel and modules. This could be accomplished by using an OTV that had the proper supplies and facilities to dock with the remote servicer in GEO and transfer supplies to it. While servicing for either scenario is expected to be a routine part of the mission plan, no doubt there will be a need for "quick" reaction service.

Requirements - The requirements for the Space Station in support of the international satellite network parallels those reported for the Land Mobile Satellite. Additional requirements would be generated if GEO remote servicing were planned. Here the discussion will be limited to the concept in which the remote servicer dwells in GEO and is itself supplied from the Space Station. The Station, serving as a launch site for an OTV, would have to store fuel and equipment modules in an acceptable environment until they are transferred to the OTV for transport to GEO and servicer resupply. To meet a "quick" reaction repair requirement, the remote servicer could have dash capability. It is possible that the servicer, by depletion,

would not have the equipment required for the emergency repair and that the Space Station would have to support an unscheduled OTV mission to properly equip the servicer.

Benefits Analysis - The benefits resulting from low earth orbit deployment and testing have been described in terms of reliability improvement. There are other aspects to the issue. With prior satisfactory demonstration of LEO activity, it is certainly possible to consider a change in current spacecraft purchasing practices to the advantage of the customer. The most well defined customer for a very large future spacecraft is Intelsat. Intelsat currently takes title to the spacecraft at launch vehicle ignition. It may be desirable to change the requirements to exchange title in LEO after spacecraft checkout and acceptance test. Of course, this is a transfer of risk as well, but with a LEO repair capability the risk should be modest. In this approach the spacecraft contractor is liable for LEO checkout, repair and their costs. The customer accepts ownership at PKM ignition.

The second consideration has to do with spacecraft insurance. If the proposed LEO activity improves the probability of spacecraft mission success, an argument for reduced insurance premiums can be developed. The cost benefits of GEO spacecraft repair and maintenance have been considered in other studies (References 2 and 3). They have shown that such repair extends spacecraft life, thus reducing the number of spacecraft that have to be built and launched to support a communications network. They report that after considering all costs of performing in orbit servicing, total program savings on the order of 15% should be possible. For an international spacecraft program costing $1 billion, this amounts to a savings of $150 million.

3.2.1.4 HF Sound Broadcast Satellite - The implications of candidate experiments in this area are described in the following paragraphs.

Market Analysis - Scores of countries operate hundreds of radio (sound) broadcast transmitters, distributing news, education and entertainment programs to a worldwide audience equipped with "shortwave" receivers. The quality and reliability of these national broadcasting services (like the VOA or the BBC) could be improved dramatically through the use of communications satellites. Though making

appropriate institutional arrangements would likely be a difficult process, it is conceivable that an international consortium (perhaps like Intelsat) could be established to finance and provide satellite program relay services on a commercial basis for a variety of potential subscribers.

Mission Description - The 25.6 to 26.1-MHz band is presently allocated to international sound broadcasting. However, the ionosphere is unstable and leaky in this band, so the band is not often used. It has been proposed (References 4 and 5) that this band be used for the same service; but using satellite-based transmitters. In this case, the transparency of the ionosphere is actually beneficial.

Stable reception is predicted for receivers operating with an elevation angle of 32 deg or more to the satellite, at least in the absence of unusually severe solar flare disturbances. For elevation angles less than 32 deg, the reception will be blocked during the day or during periods of high sunspot numbers (refer to Reference 1).

The global coverage antenna of the first generation satellite could be realized by means of a seven-element array of 23-m long helixes. The 3 deg spot-beam antenna of the third generation satellite could be an open-mesh reflector fed by helix feed elements.

Some of the principal technical characteristics associated with a plausible evolutionary series of spacecraft are as follows:

	GENERATION		
	I	II	III
Audio S/N, Db	36	39	39
Channels	5	10	40
Coverage	Global	Hemi	Spot
Aperture, MxM	50 x 50	50 x 300	300 x 300
Prime Power	3.5	7	16

As shown above, satellites for HF sound broadcasting require large antennas and consume much power. The power levels are predicated on the use of FM. For global coverage, each channel would require a 300-W transmitter. If AM were used, the power levels would be one or two orders of magnitude greater.

Antenna diameters for HF sound broadcasting fall into the 50- to 300-m range. They would have to be folded and stowed for transportation to LEO, then deployed and tested prior to ascent to GEO.

Requirements - Requirements (except for schedule details) for the HF Sound Broadcast Satellite Mission are similar to those described for the Land Mobile Satellite. The significant time-phased requirements are given in Fig. 3.2-13.

	'94	'95	'96
SATELLITES TRANSPORTED	–	2	–
SATELLITE MASS TRANSPORTED, kg	–	10,000	–
SATELLITES OPERATING	–	2	2
MATERIALS TRANSPORTED, kg	–	–	–
CREW TIME* MAN-hr	–	2,880	–
OPERATING POWER, kW	–	1.0	–
POWER DUTY CYCLE	–	0.2	–
LENGTH FOR STS, m	–	12	–

*8 MAN-HR PER DAY EACH SATELLITE
R83-0663-214(T) V83-0165-371(T)

Fig. 3.2-13 Schedule for HF Broadcast Satellite

3.2.1.5 **Communications Satellite Traffic to GEO** - The communication satellite traffic to geostationary orbit is part of the traffic model used to evaluate OTV operations that begin in 1993.

A variety of different data sources was used in the formulation of the total free-world commercial communications satellite launch forecast. The Battelle report, "Outside User Payload Model," dated July 1982, was used as the strawman. This schedule provided a forecast of International Communications, U.S. Domestic Communications and Foreign Domestic and Regional Communications up to the year 1997. This schedule was then modified by information obtained from spacecraft manufacturers, Space System operators, foreign organizations, NASA Shuttle mission planners, and the projected launch schedules for the Shuttle, Delta and Ariane. The replacement criterion used in the model formulation was that satellite replacement would occur at 80 to 85% of expected life.

The share of the world total that would be captured by the STS was determined by analysis of an adequate number of samples. Shares captured by the STS are:

- 45% of the International total
- 95% of the U.S. total
- 35% of the Foreign total.

The resulting traffic for each spacecraft mass category is given in Fig. 3.2-14. The International, Land Mobile and HF Broadcast satellites discussed in the previous subsections are included.

		EXPENDABLE PROPULSION			OTV OPERATIONS								
MASS, kg	USERS	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000	SUB TOTALS
700	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				2	2	2	2	3	2	1	0	14
	FOREIGN				1	2	0	2	1	1	1	0	8
	TOTAL				3	4	2	4	4	3	2	0	22
1000	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				0	1	1	1	1	0	0	0	4
	FOREIGN				0	1	1	1	1	1	0	1	6
	TOTAL				0	2	2	2	2	1	0	1	10
1500	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				4	6	6	3	0	3	2	1	25
	FOREIGN				2	1	1	1	1	0	1	0	7
	TOTAL				6	7	7	4	1	3	3	1	32
2300	INTERNATIONAL				0	0	0	0	0	0	0	0	0
	U.S.				2	3	0	2	2	1	2	2	14
	FOREIGN				0	0	1	0	0	0	1	0	2
	TOTAL				2	3	1	2	2	1	3	2	16
2800	INTERNATIONAL				1	1	1	1	1	0	1	0	6
	U.S.				0	0	0	0	0	0	0	0	0
	FOREIGN				0	0	0	0	0	0	0	0	0
	TOTAL				1	1	1	1	1	0	1	0	6
3100	U.S.				0	0	0	1	0	0	0	0	1
3800	INTERNATIONAL				0	0	0	0	0	2	2	2	6
10000	U.S. LAND MOBILE				0	0	0	0	0	2	1	0	3
5000	U.S. HF SOUND BROADCAST				0	0	2	0	0	0	0	0	2
TOTALS FOR YEAR					12	17	15	14	10	12	12	6	98
R83-0663-215(T)													V83-0165-269(T)

Fig. 3.2-14 Commercial Communications Traffic Using STS

3.2.2 Materials Processing Missions

The materials processing missions are considered in two categories, research and development (R&D) and production. The R&D for production in the 90s presumably must have been completed in the 80s, but a continual R&D effort in space is required. Two types of R&D are envisioned. The first is aimed at the development of a commercially viable on-orbit service process or product. The second is R&D conducted on-orbit, but aimed at gaining fundamental understanding with application terrestrially. A generic laboratory with ample facilities for commercial R&D is treated as an individual mission.

Materials processing missions generally have two predominant requirements, low gravity and high electrical power, both for long continuous durations (1 to 20 days). The two obvious options for meeting these requirements are an unmanned free flyer (Fairchild Leascraft and ESA Eureca are examples) or a manned facility. The unmanned free flyer is difficult to service, while the manned facility has difficuity in providing continuous low gravity conditions over long durations. Requirements of equipment mass, equipment power and crew manhours are related to the selected option. Requirements estimates were made based on the manned facility, but are considered applicable for the other case if the unmanned free flyer is serviced in a shirt sleeve environment on a manned facility.

The selected production missions together with the marketing summary and estimated requirements of each production unit (furnace, apparatus, reactor, etc), are listed in Fig. 3.2-15 and 3.2-16 respectively. These missions are based on extrapolations of present markets and state-of-the art processing. Each production unit has a maximum annual output. Whenever annual output is greater than the unit maximum, multiple units are employed. The research and development units and their requirements are discussed in the following subsection.

3.2.2.1 Research & Development Materials Processing - Research and Development missions and hardware were selected on the basis of relevance with respect to terrestrial production and substantive benefit from low-g processing.

Market Analysis - The commercial R&D materials processing laboratory will conduct two types of programs. The first is research and development aimed at the development of a commercially viable on-orbit service, process or product. The second is research and development conducted on-orbit, but aimed at gaining fundamental understanding of commercially significant processes, properties or products, with application on the ground.

Results from our Space Station Constituency Development activities indicate that the latter projects will greatly outnumber the former, though the market is undefined. The users are high technology companies, with sizable research efforts and resources. These companies are most likely to be in the metals, glass, crystal growth, electronics, biologicals and pharmaceutical areas

PRODUCT	ANNUAL MATERIALS REQD/Kg	YIELD	MATERIALS SALES PRICE/Kg	PRODUCT SALES PRICE/Kg	ANNUAL SALES
HgCdTe	1104	0.60	\$380K	\$600K	\$397M
BULK GaAs	1695	0.60	\$36[illegible]	\$60K	\$61M
THIN FILM GaAs	3012	0.20	\$120K	\$600K	\$360M
PROTEIN CRYSTALS	695	0.000014	\$14K	\$1000M	\$10M
ISOENZYMES	360	0.01	\$573K	\$57.3M	\$206M
BIOLOGICALS	3000	0.04	\$67K	\$1.68M	\$200M
X-RAY TARGETS	2220	0.0[illegible]	\$18K	\$20K	\$40M
LATEX SPHERES	380	0.75	TBD	TBD	TBD

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Fig. 3.2-15 Marketing Summary, Year 2000 Commercial Materials Processing (1984\$)

PROCESS	g-LEVEL g_o	MASS kg	VOL m^3	OPER POWER kW	POWER DUTY CYCLE	PROCESS TIME DAYS	SERV TIME* MAN HR
PRODUCTION OF HgCdTe	$<10^{-4}$	800	3	3.5	0.96	11	4
PRODUCTION OF BULK GaAs	$<10^{-4}$	900	4.5	7.0	0.96	11	4
PRODUCTION OF THIN FILM GaAs	$<10^{-4}$	700	8	6.5	0.83	1	4
PRODUCTION-PROTEIN CRYSTALS	$<10^{-4}$	300	1	1.0	0.98	21	8
ISOENZYME SEPARATIONS	10^{-3}	200	0.5	0.4	0.60	0.1-1	0.15
PRODUCTION OF BIOLOGICALS	10^{-4}	410	4.4	0.7	0.97	1	3
X-RAY TARGET PRODUCTION	10^{-4}	2000	16	15	0.50	1/3	2
PRODUCTION OF LATEX SPHERES	10^{-4}	3,000	3	1.0	0.99	1	2

*INCLUDES START UP, SHUT DOWN, LOADING, UNLOADING & MONITORING

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Fig. 3.2-16 Requirements for Each Materials Processing Production Unit

Mission Description - The primary attributes of space that will be exploited in commercial materials processing R&D are reduced gravity and a low vacuum with essentially infinite pumping capacity. The latter experiments are likely to be conducted behind a "wake shield" removed some distance from the local contamination of the Space Station.

The advantage of processing in the vacuum of space is two-fold: the vacuum achieved is expected to be very low (down to 10^{-13} torr) and the pumping rates high, and the contaminant species will be different than in terrestrial systems (Ar and He instead of O_2 and N_2).

The advantage of conducting solidification and bioseparation processes in low-g is that gravitationally driven convection is damped and the solidification or separation processes will be conducted under diffusion-controlled conditions. This will eliminate convection-dependent thermal and compositional fluctuations during the process and result in an improved chemical homogeneity and, in the case of single crystals, a reduced fault density in the product.

A materials processing laboratory aboard a manned Space Station will contain many of the same facilities as a materials science and engineering laboratory on earth. We have selected 11 pieces of research apparatus for our commercial materials processing laboratory; these are tabulated in Fig. 3.2-17. These pieces of apparatus fall into 3 generic categories: crystal growth; containerless processing; and biological separation. Of the 11 pieces of apparatus, 8 are described and illustrated in subsequent commercial and science missions. These include directional solidification furnace, liquid phase epitaxy furnace, acoustic levitation furnace, electrostatic levitation furnace, electromagnetic levitation furnace, protein crystal reactor, continuous flow electrophoresis system, and gel electrophoresis system. The remaining systems are illustrated schematically in Fig. 3.2-18.

Czochralski growth (Fig. 3.2-18A) is the most commercially used crystal growth technique terrestrially. As a consequence, there is much interest in understanding and improving this process. Similarly, it is the process that large segments of the crystal growth community would feel most comfortable with in attempting to apply their technology during orbital processing

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SINGLE UNITS	MASS KG	VOLUME m^3	OPER. POWER KW	MATERLS PER YR, KG	CREW MAN-HR PER YR
DIRECT SOLIDIFICATION FURNACE	1000	4.0	4.0	680	200
CZOCHRALSKI FURNACE	1000	4.0	4.0	600	200
LIQUID PHASE EPITAXY FURNACE	750	3.0	6.0	20	200
SOLUTION CRYSTAL GROWTH FURNACE	500	2.5	2.5	6	50
ACOUSTIC LEVITATION FURNACE	600	4.0	10.0	10	600
ELECTROSTATIC LEVITATION FURNACE	600	4.0	7.5	10	600
ELECTROMAGNETIC LEVITATION FURNACE	600	5.5	10.0	10	600
FLOAT ZONE FURNACE	600	3.5	7.5	600	200
CONTINUOUS FLOW ELECTROPHORESIS UNIT	500	17.5	4.0	1600	100
GEL ELECTROPHORESIS UNIT	800	1.5	1.5	150	100
PROTEIN CRYSTALS REACTOR	100	4.0	1.0	<<1	200

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Fig. 3.2-17 Commercial Materials Processing Laboratory – Unit Requirements

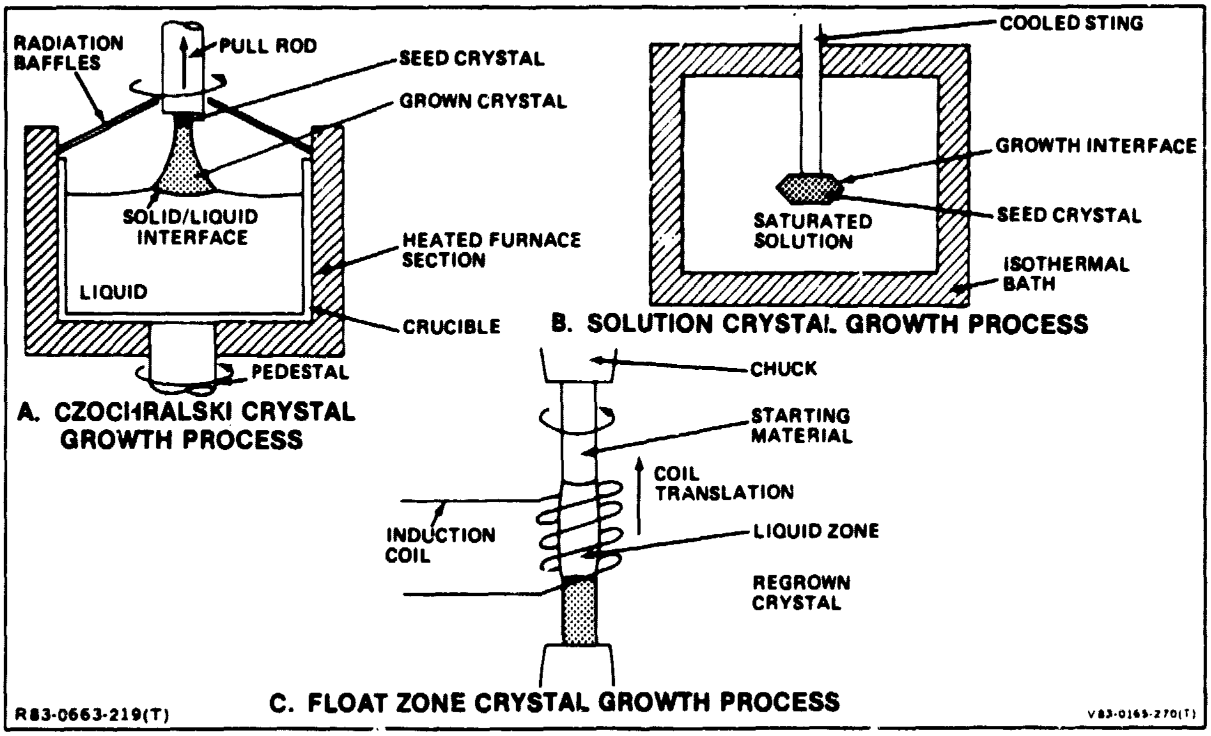

Fig. 3.2-18 Materials Processing Research & Development Apparatus

A Czochralski growth system consists of a liquid bath of molten alloy that is brought in contact with a small seed crystal of the material to be grown. The seed crystal is then slowly "pulled" away from the bath, initially building up the diameter of the growing crystal to the desired size, and then growing under steady-state conditions. The sample and bath are usually both rotated or counter-rotated in the interests of themal symmetry. This process may have to be modified in space in order to constrain the melt in a well defined location. The melt may be heated by resistance or induction heaters, and radiation baffles are frequently used to reradiate heat lost from the surface of the melt.

Solution crystal growth (Fig. 3.2-18B) is generally accomplished in an isothermal saturated solution bath with a slightly undercooled seed crystal positioned in the bath on a "sting." The new crystal layers then grow epitaxially on the seed. This is a very slow process, usually taking one to three months to grow a high quality product.

The float zone process (Fig. 3.2-18C) is similar in intent to directional solidification. In the float zone system, a molten zone is passed, at a constant velocity, down the length of the sample. In the absence of the gravitational body force, the surface tension is sufficient to contain the molten zone. In space, zone geometries up to the Rayleigh instability limit are feasible. It is anticipated that the shape of this molten zone will be more uniform than in 1g. As in the case of Czochralski growth, rotation and counter-rotation are sometimes used in the interests of improved themal symmetry.

The brief descriptions above summarize the processes and apparatus involved in key materials processing in space applications. Turning now to the requirements for utilizing this apparatus, the size, mass and frequency of materials loaded and unloaded is experiment unique. The production missions describe resupply requirements in detail. The three cases that are not covered immediately follow. The float zone requirements are similar to those for directional solidification of HgCdTe. Czochralski resupply requirements are somewhat greater, to grow similarly sized crystals, due to the fact that the material reservoir from which the crystals are "pulled" is larger than for directional solidification and the material crucible that houses the molten material is also considerably greater. A factor of 2x increase in the directional solidification resupply requirements will adequately account for this

difference. The solution crystal growth furnace should be reequipped with modules of fresh solution. Many of those of interest are aqueous solutions. If a growth period of one month is anticipated, 12 modules/year/furnace will be needed. If each were 10-liter modules, the module weight would be about 10 kg/module, or 120 kg/year.

Requirements - The mass, volume and operating power for each process is summarized in Fig. 3.2-17. The Directional Solidification, Czochralski, and Float Zone processes are scaled to produce 5-cm dia crystals at an average processing velocity of 3 cm/hr. The Liquid Phase Epitaxy process is scaled to produce approximately 1000 thin films annually, each 500 μm thick (including substrate) and 10 cm in diameter. The levitators are estimated to process one 1.25 cm sphere/hour, and the solution crystal growth is assumed to occur at 1 mm/day. The electrophoresis systems are scaled to perform the continuous flow and gel electrophoresis operations called for by MDAC (Reference 6) and GE (this report), respectively. The crew involvement is considered to be the minimum required. Utilizing a skilled materials scientist or technician on orbit, or with telepresence, would greatly increase this manpower requirement.

The total laboratory requirements are summarized in the NASA data sheets (Part IV). Significant time-phased requirements, unit mass transported materials transported, cross crew-time and electrical power, for each laboratory unit are given in Fig. 3.2-19 through 3.2-22, respectively. The electrical power duty cycle for the total laboratory is low (0.25) assuming a large percentage of time will be spent setting up experiments, exchanging information with the ground and analyzing results.

Benefits Analysis - The presence of man on a Space Station will significantly change the basic R&D mode of operation in space. Constraints on equipment will be lessened. More electrical power and longer continuous periods of experiment time in microgravity will be available. In particular, the existence of man in the Space Station - presumably a trained professional scientist or one trained to interact by communication in real-time with professional scientists - would allow for an interactive mode of materials research in space that is much closer to that now conducted in laboratories on earth. Space Laboratories in a manned Space Station could be equipped not only to observe and collect data but to alter and adapt experiments based on observation and results. No longer would it be necessary to plan (or

SINGLE UNITS	'90	'91	'92	'93	'94	'95
DIRECT SOLIDIFICATION FURNACE	1000	–	–	–	–	–
CZOCHRALSKI FURNACE	–	1000	–	–	–	–
LIQUID PHASE EPITAXY FURNACE	–	–	750	–	–	–
SOLUTION CRYSTAL GROWTH FURNACE	–	–	–	500	–	–
ACOUSTIC LEVITATION FURNACE	–	600	–	–	–	–
ELECTROSTATIC LEVITATION FURNACE	–	–	–	–	600	–
ELECTROMAGNETIC LEVITATION FURNACE	–	–	–	600	–	–
FLOAT ZONE FURNACE	–	–	–	–	600	–
CONTINUOUS FLOW ELECTROPHORESIS UNIT	500	–	–	–	–	–
GEL ELECTROPHORESIS UNIT	–	800	–	–	–	–
PROTEIN CRYSTALS REACTOR	–	–	100	–	–	–
TOTAL MASS OF UNITS TRANSPORTED	1500	2400	850	1100	1200	–
NUMBER OF UNITS OPERATING	2	5	7	9	11	→
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Fig. 3.2-19 Commercial Materials Processing Laboratory – Mass of Units Transported, kg

guess) in advance virtually all aspects of the experiment. Neither would it be necessary to depend so heavily on tremendously expensive but highly restrictive general-purpose hardware. Experience so far in the MPS program has led to limited painstaking progress achieved in the non-interactive mode. The availability of the interactive mode would make possible the rapid progress that has long been hoped for, and which is necessary for commercially viable R&D efforts.

SINGLE UNITS	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
DIRECT SOLIDIFICATION FURNACE	600	600	600	600	600	600	600	600	600	600	600
CZOCHRALSKI FURNACE		600	600	600	600	600	600	600	600	600	600
LIQUID PHASE EPITAXY FURNACE			20	20	20	20	20	20	20	20	20
SOLUTION CRYSTAL GROWTH FURNACE				6	6	6	6	6	6	6	6
ACOUSTIC LEVITATION FURNACE		10	10	10	10	10	10	10	10	10	10
ELECTROSTATIC LEVITATION FURNACE					10	10	10	10	10	10	10
ELECTROMAGNETIC LEVITATION FURNACE				10	10	10	10	10	10	10	10
FLOAT ZONE FURNACE					600	600	600	600	600	600	600
CONTINUOUS FLOW ELECTROPHORESIS UNIT	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
GEL ELECTROPHORESIS UNIT		150	150	150	150	150	150	150	150	150	150
PROTEIN CRYSTAL REACTOR			1	1	1	1	1	1	1	1	1
	2200	2960	2981	2997	3607	3607	3607	3607	3607	3607	3607

Fig. 3.2-20 Commercial Materials Processing Laboratory – Materials Transported for Units, kg

SINGLE UNITS	'90	'91	'92	'93	'94	'95	'96	'97	'98	'98	2000
DIRECT SOLIDIFICATION FURNACE	200	200	200	200	200	200	200	200	200	200	200
CZOCHRALSKI FURNACE	–	200	200	200	200	200	200	200	200	200	200
LIQUID PHASE EPITAXY FURNACE	–	–	200	200	200	200	200	200	200	200	200
SOLUTION CRYSTAL GROWTH FURNACE	–	–	–	50	50	50	50	50	50	50	50
ACOUSTIC LEVITATION FURNACE	–	600	600	600	600	600	600	600	600	600	600
ELECTROSTATIC LEVITATION FURNACE	–	–	–	–	600	600	600	600	600	600	600
ELECTROMAGNETIC LEVITATION FURNACE	–	–	–	600	600	600	600	600	600	600	600
FLOAT ZONE FURNACE	–	–	–	–	200	200	200	200	200	200	200
CONTINUOUS FLOW ELECTROPHORESIS UNIT	100	100	100	100	100	100	100	100	100	100	100
GEL ELECTROPHORESIS UNIT	–	100	100	100	100	100	100	100	100	100	100
PROTEIN CRYSTALS REACTOR	–	–	200	200	200	200	200	200	200	200	200
TOTAL CREW TIME	300	1200	1600	2250	3050	3050	3050	3050	3050	3050	3050

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Fig. 3.2-21 Commercial Materials Processing Laboratory – Crew Time for Units, Man-hr

SINGLE UNITS	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
DIRECT SOLIDIFICATION FURNACE	4	4	4	4	4	4	4	4	4	4	4
CZOCHRALSKI FURNACE	–	4	4	4	4	4	4	4	4	4	4
LIQUID PHASE EPITAXY FURNACE	–	–	6	6	6	6	6	6	6	6	6
SOLUTION CRYSTAL GROWTH FURNACE	–	–	–	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
ACOUSTIC LEVITATION FURNACE	–	10	10	10	10	10	10	10	10	10	10
ELECTROSTATIC LEVITATION FURNACE	–	–	–	–	7.5	7.5	7.5	7.5	7.5	7.5	7.5
ELECTROMAGNETIC LEVITATION FURNACE	–	–	–	10	10	10	10	10	10	10	10
FLOAT ZONE FURNACE	–	–	–	–	7.5	7.5	7.5	7.5	7.5	7.5	7.5
CONTINUOUS FLOW ELECTROPHORESIS UNIT	4	4	4	4	4	4	4	4	4	4	4
GEL ELECTROPHORESIS UNIT	–	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
PROTEIN CRYSTALS REACTOR	–	–	1	1	1	1	1	1	1	1	1
TOTAL OPERATING POWER, KW	8	23.5	30.5	43	58	58	58	58	58	58	58
DUTY CYCLE FOR LABORATORY	0.25										
POWER REQUIRED	2	5.9	7.6	10.8	14.5						

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Fig. 3.2-22 Commercial Materials Processing Laboratory – Operating Power & Duty Cycle of Units

3.2.2.2 Production of Hg-Cd-Te - There are many single crystals that are difficult to grow terrestrially. The most successful terrestrial bulk growth techniques are Bridgman and Czochralski. We have selected modified Bridgman growth of Hg-Cd-Te crystals as a high return process benefited by low-g processing.

Market Analysis - Hg-Cd-Te, mercury-cadmium-telluride (MCT), satisfies more of the IR sensor requirements listed below than any other detector material:

- High detectivity
- Fast response
- Near-ambient operating temperature
- Long life
- High reliability
- Resistance to thermal cycling
- Wavelength choice for peak response
- Resistance to radiation.

Therefore, MCT is uniquely suited for the fabrication of junction detector devices and imaging infrared focal-plane arrays using monolithic integrated circuits (References 7 and 8).

MCT is supplied by 12 companies, but the company with the largest market share is Cominco American. Hughes, Honeywell, Rockwell, and Texas Instruments all manufacture MCT, but largely for in-house programs (Reference 9). Purchasers are companies that manufacture focal plane detector arrays, single-element detectors and small specialized detector arrays. Applications are envisioned in heterodyne receivers in infrared laser systems for range determinations, three-dimensional imaging, target acquisition and tracking, and advanced optical communication systems.

The 1982 production of MCT was approximately 100 kg and the market value was in the order of $300M. The average cost per unit weight was thus $3M/kg. We have assumed that the cost/unit weight of material produced by Space Station will be a factor of 3 lower in 1990 ($1M/kg) and a factor of 5 lower in 2000 ($600K/kg).

The MCT production is expanding at about 25% annually. Production is projected to be 600 kg in 1990 and 5600 kg in 2000. The present plan calls for 10% market penetration on the premium end of the market. The 1990 space production that we envision is 60 kg, with a market value of \$60M (\$1M/kg), whereas the 2000 space production is projected to be 550 kg with a market value of \$333M (\$600K/kg).

Mission Description - The reason for growing bulk Hg-Cd-Te crystals in space is that the low-g orbital environment will damp the gravitationally driven thermo-solutal convection that is detrimental to the terrestrial product (Reference 10). Growth under diffusion-controlled conditions will result in improved chemical homogeneity over the length of the crystal (increasing yield), and will have reduced fault densities (improving performance and lifetime).

The bulk crystal growth process selected is Bridgman-Stockbarger plane-front directional solidification. This process involves translating a sample ampoule at a constant velocity through a furnace system with a specific thermal profile. This profile is shown schematically in Fig. 3.2-23.

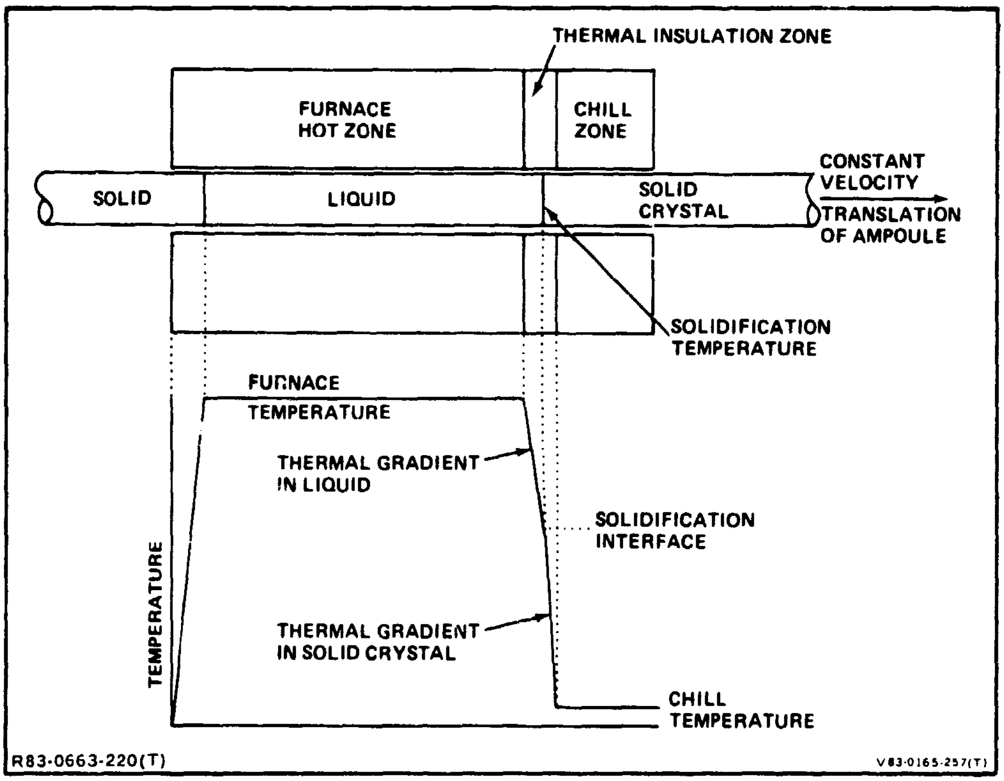

Fig. 3.2-23 Bridgman – Stockbarger Directional Solidfication Process

The primary role of man will be to serve as a technician who will load and unload the furnace periodically, monitor the process while in progress, maintain inventories and production schedules, refurbish and repair the furnace and related hardware and instrumentation and perform on-board data consolidation.

Requirements - The critical requirements for the payload element are: continuous low-g, continuous power and continuous heat rejection. The components needed in a Bridgman-Stockbarger furnace system are a power supply or conditioner, a process control unit, a data acquisition/telemetry system, cooling loop, heat rejection system and support framework. The system is estimated to be 1 x 2 x 1.5 m, weighing 800 kg (all inclusive) and will consume 3.5 kW average (4.2 kW peak), with comparable cooling requirements. The power required is based on data provided by a custom furnace manufacturer (Reference 11). These requirements are shown in Fig. 3.2-24.

• G LEVEL	10^{-4} to 10^{-7}
• PRODUCTION INGOT	
– WEIGHT AT 7 g/cm^3	2.75 kg
– DIAMETER	5 cm
– LENGTH	25 cm
– AVERAGE POWER	3.5 kW
– TIME TO GROW (AT 0.1 cm/HR)	250 Hr
• SINGLE FURNACE	
– WEIGHT	800 kg
– AVERAGE POWER REQUIRED	3.5 kW
– NUMBER INGOTS PER YR	33
– WEIGHT OF INGOTS PER YR	91.3 kg
– USABLE WEIGHT PER YR, 60% YIELD	54.8 kg
• ESTIMATE OF PRESENT U.S. MARKET	
– ANNUAL OUTPUT	100 kg
– NUMBER OF FURNACES REQUIRED	2.0

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Fig. 3.2-24 HgCdTe Requirements, Commercial Production by Directional Solidification

The g requirements are based on low-g experience and on calculations of fluid flow velocities as a function of g-level, by the contact listed on the summary data sheets.

The data required are sample temperatures, furnace temperatures, coolant loop pressure and temperature, ampoule translation velocity, time base, and g-level (three-axis at two locations). Each data point should be at least eight characters, recorded as a data pair with time the coupled variable. For the Hg-Cd-Te growth process described, the data acquisition rate would be 1 data pair every 10

sec/channel. For 20 channels and a 250-hr process time, the data storage requirement would be of the order of 1 to 10 Mbit.

G-level measurement should be measured up to 100 Hz in three axes. It would be best to measure the g-level at each end of the furnace, and computer programs could then interpolate to the vicinity of the solidification interface. These data might be available from the Space Station facility or Space Station materials processing laboratory, if on board.

Telepresence might have some utility, both with respect to routine process monitoring and safety should an ampoule failure occur. This would require a high bit rate, but no storage.

The primary consumables on orbit will be power and the sample ampoules that are processed. Each 3.5 kg ampoule will house a 2.75 kg crystal sample. The furnace cycles a sample in 11 days, requiring about 100 kg of ampoules annually. Each ampoule will be about 4-5 cm in diameter and 75 cm long. The coolant is envisioned to be a closed loop system.

The unit requirements for this mission are summarized in the NASA Payload Element Data Sheets, Part IV of this volume. The significant time-phased requirements are given in Fig. 3.2-25 for the estimated annual productions.

	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
FURNACES TRANSPORTED	1	1	2	2	1	2*	2*	3*	3*	1*
FURNACE MASS TRANSP, kg	800	800	1600	1600	800	1600	1600	2400	2400	800
FURNACES OPERATING	1	2	4	6	7	8	9	10	11	11
MATERIALS TRANSPORTED, kg	91.3	183	365	548	639	730	822	913	1004	1004
CREW TIME **, MAN-HR	132.7	265	531	796	929	1062	1194	1327	1460	1460
OPERATING POWER, kW	3.5	7.0	14.[illegible]	[illegible]1.0	24.5	28.0	31.5	35.0	38.5	38.5
POWER DUTY CYCLE	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

* INCLUDES REPLACEMENT OF EQUIPMENT 5 YEARS OLD
**4 HR EVERY 11 DAYS PER FURNACE

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Fig. 3.2-25 Commercial Production Schedule for HgCdTe

Benefit Analysis - Two alternatives were selected for comparison, the Shuttle plus 5-kW free flyers and the Space Station with larger 22 kW industrial platforms. Another alternative, the Space Station plus 5-kW free flyers, was considered but discarded since preliminary analysis indicated that costs would be between those of the two selected alternatives.

The comparative costs are based on the average product production for the 10-year time span of the production schedule, and are shown in Fig. 3.2-26. The number of furnaces operating, furnaces launched, power required, etc, are all 10-year averages and are shown in the lower part of Fig. 3.2-27. The number of flyers/platforms required then is the average power required divided by the power of the vehicle. Cost groundrules are as presented earlier in Fig. 3.2-2, and calculations are shown in Fig. 3.2-27.

Results are shown in Fig. 3.2-26, and show a saving of $48M per year by using the Space Station plus industrial platforms. This saving can mainly be attributed to:

- More efficient Shuttle manifesting when dispatched to the Space Station
- Fewer Shuttle rendezvous
- Lower facility costs because, although the platform cost is higher, the number required is much less than the number of free flyers.

3.2.2.3 Commercial Production of Bulk Ga-As - We have selected modified Bridgman growth of Ga-As single crystals as a viable commercial process because of the large market potential and the benefits afforded this process by low-g processing.

Market Analysis - Two forms of Ga-As are presently marketed, conductive and semi-insulating. Semi-insulating (SI) material finds application in high power and low noise field effect transistors (FETs) and monolithic integrated circuits (MICs).

Conductive Ga-As finds application in microwave devices (Gunn diodes, mixers, varacters and IMPATTS), optical devices (LEDs, VLEDs and detectors), lasers (laser materials, lenses and windows), and as solar cells. Bulk Ga-As, cut into 375 to 750 μm thick wafers, is used in all of these applications, usually with some additional surface processing done by liquid phase epitaxy (LPE), vapor phase epitaxy

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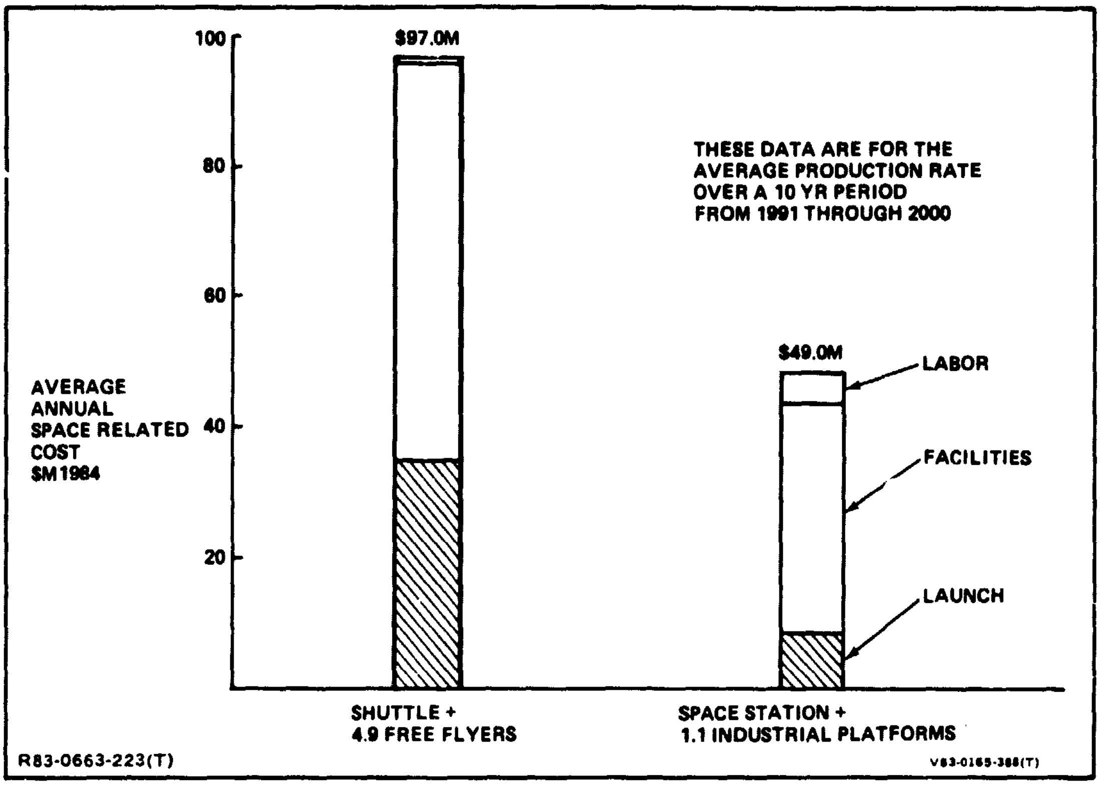

Fig. 3.2-26 Comparative Costs of HgCdTe Production

	SHUTTLE + 5 KW FREE FLYER (4.9 REQD)	$M	SPACE STATION + 22 KW INDUS PLATFORM, (1.1 REQD)	$M
LAUNCH				
MATERIALS	$2479/.7 PER kg	2.2	$2479/.9 PER kg	1.7
FURNACES	$2479/.7 PER kg	11.1	$2479/.9 PER kg	5.9
RENDEZVOUS	4.9 x 2/YR x $.88M	8.6	.09 x $.88M	0.1
LOITER	4.9 x 2/YR x 2d x $.66M	12.9		–
FACILITY				
SHARE OF FLYER/PLATFORM	4.9 x $200M/20 YR	49.0	1.1 x $500/20 YR	27.5
FURNACE DEVELOPMENT	$30M/20 YR HIGHLY	1.5	$20M/20 YR	1.0
FURNACE PRODUCTION	$6M x 1.8 AUTOMAT	10.8	$4M x 1.8	7.2
LABOR				
FLYER/PLATFORM BERTHING/ DESPATCHING	INCLD IN RENDEZVOUS	–	1.1 x 33 x 20 MAN-HR x $3400	2.5
FURNACE OPERATIONS	6.9 x 2 x 20 MAN-HR x $3400	0.9	6.9 x 33 x 4 MAN-HR x $3400	3.1
COMPARATIVE TOTAL		97.0		49.0

MISSION INPUT DATA	NO.	MASS kg	POWER REQD KW	MATERIALS kg	USEFUL OUTPUT kg	PROCESS TIME DAYS
SINGLE FURNACE	1.0	800	3.5	91.3	54.8	11
FURNACES OPERATING	6.9	–	24.5	630	378	–
FURNACES + ASE LAUNCHED	1.8	2140	–	–	–	–

R83-0663-224(T) V83-0165-383(T)

Fig. 3.2-27 Average Annual Costs for 10 Years of HgCdTe Production

(VPE), or ion implantation. Gallium arsenide has particular advantage for space-based applications (solar cell, optical surveillance devices or microwave devices) because radiation damage is self-annealing and the devices can operate at higher efficiencies and higher temperatures. Bulk Ga-As is commercially supplied by about a dozen companies. The companies with the largest market segments are the Gallium Arsenide Products division of MACOM, and Cominco American. It is supplied either as a single crystal ingot or as wafers, depending on the preference of the user. The wafers are most frequently used as substrates for secondary processing operations. These materials are supplied to manufacturers of the system or subsystem hardware for the previously listed applications. Prominent users are the makers of missiles, radar, communication, surveillance, laser and integrated circuit systems.

The annual production of Ga-As in 1982 was 3000 kg of conductive and 1750 kg of semi-insulating material. The above estimates include LED and FET applications. The conductive market is expanding at about 25% annually and the semi-insulating market at about 50% annually. The over-all market is expanding at 40% annually. The dollar value of these products is hard to estimate because of the high value-added in the final system. Materials costs range from a low of about $22,000/kg to a high of $2.2M/kg depending on final application and materials specification. If a median price of $110,000/kg is assumed, the present market is about $500 million, annually

The market projection for bulk Ga-As is assumed to be 21,800 kg in 1991 and 162,300 kg in the year 2000. A market penetration of 1% is assumed, as only the premium portion of this market can be addressed. Consequently, the bulk production for the year 2000 is assumed to be 16,230 kg. The present average price per kg is $110,000; however, the price is dropping rapidly and, by the year 2000, the premium bulk material is envisioned to be selling for $36,000/kg and the cut and polished wafers for $60,000/kg. The product value for the year 2000 is thus $61M.

Mission Description - The advantage of processing bulk Ga-As in space is that the low-g orbital environment will damp the gravitationally driven thermo-solutal convection. Production of undoped Ga-As would be predicated on a reduced fault or defect density resulting from the diffusion controlled growth conditions. Doped

Ga-As would benefit, in addition, from more uniform solute distribution, as discussed in the Mercury-Cadmium-Telluride section.

The bulk crystal growth process would be identical to that described in the Mercury-Cadmium-Telluride section and which is shown schematically in Fig. 3.2-23. The data requirements (type, number and frequency) are identical, and man's role is also unchanged. The resupply requirements are approximately 3x greater because of the increased production throughput, as compared to Hg-Cd-Te. The increased throughput is largely accomplished by increasing the crystal diameter and the furnace system must be scaled up accordingly.

Requirements - The rationale for scaling up this operation relative to Mercury-Cadium-Telluride is that the potential market is considerably greater, thus a reasonable market penetration demands increased production. In addition, the anticipated price per unit weight of bulk Ga-As is lower than that of Mercury-Cadmium-Telluride and as a result more must be produced to offset the on-orbit and transportation expenses. The cost differential in hardware is considered to be negligible.

The specific requirements for this process are included in the attached NASA data sheets. It is anticipated that in the 90s this requirement will increase at about 40% per year if a constant market share is to be maintained.

The unit requirements for this mission are summarized in the NASA Payload Element forms (Part IV). The significant time-phased requirements are given in Fig. 3.2-28 for the estimated annual productions.

Benefit Analysis - The alternatives and procedures are the same as those discussed for Hg-Cd-Te in Subsection 3.2.2.2. Results are shown in Fig. 3.2-29 and 3.2-30. The benefit of the Space Station results from the same reasons mentioned for Hg-Cd-Te; the process is similar to the Hg-Cd-Te process.

3.2.2.4 Commercial Production of Thin Film Ga-As - Ga-As is produced in a bulk form, as previously described, and as thin films. Of the thin film processes, only

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	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
FURNACES TRANSPORTED	1	0	0	1	0	1*	1	1	1*	1
FURNACE MASS TRANSP, kg	900	–	–	900	–	900	900	900	900	900
FURNACES OPERATING	1	1	1	2	2	2	3	4	4	5
MATERIALS TRANSPORTED, kg	339	339	339	678	678	678	1017	1356	1356	1695
CREW TIME **, MAN-HR	133	133	133	265	265	265	398	531	531	664
OPERATING POWER kW	7	7	7	14	14	14	21	28	28	35
POWER DUTY CYCLE	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

* INCLUDES REPLACEMENT OF EQUIPMENT 5 YEARS OLD
**4 HR EVERY 11 DAYS PER FURNACE

R83-0663-225(T) V83-0165-003(T)

Fig. 3.2-28 Commercial Production Schedule for Bulk GaAs

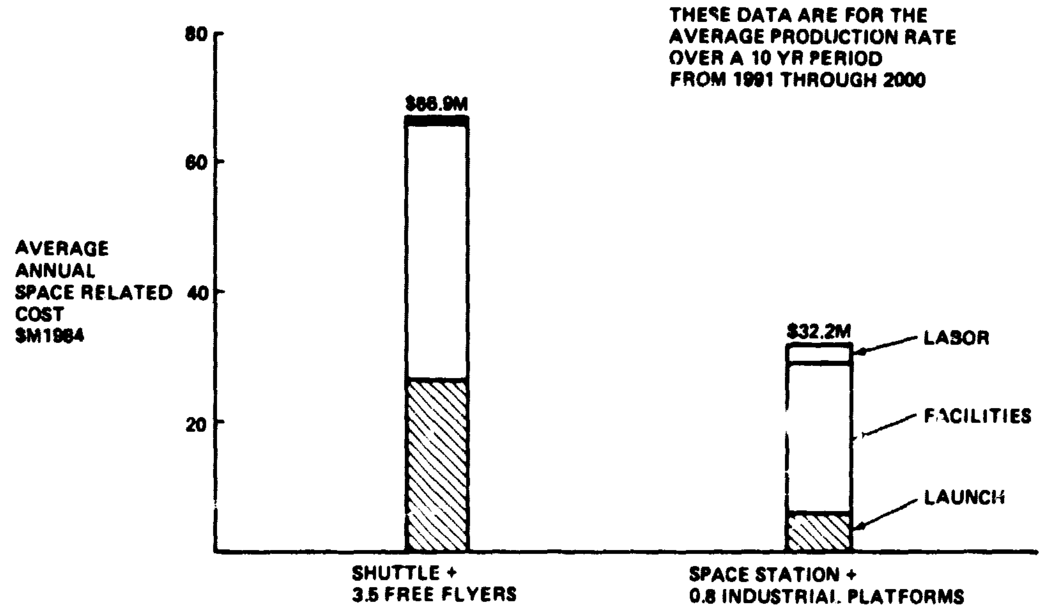

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Fig. 3.2-29 Comparative Costs of Bulk GaAs Production

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	SHUTTLE + 5 KW FREE FLYER (3.5 REQD)	$M	SPACE STATION + 22 KW INDUS PLATFORM (0.8 REQD)	$M
LAUNCH				
MATERIALS	$2479/.7 PER kg	3.0	$2479/.9 PER kg	2.3
FURNACES	$24. ?/.7 PER kg	7.5	$2479/.9 PER kg	3.1
RENDEZVOUS	3.5 x 2/YR x $.88M	6.2	.09 x $.88M	0.1
LOITER	3.5 x 2/YR x 2d x $.66M	9.2		–
FACILITY				
SHARE OF FLYER/PLATFORM	3.5 x $200M/20 YR	35.0	0.8 x $500M/20 YR	20.0
FURNACE DEVELOPMENT	$30M/20 YR HIGHLY	1.5	$20M/20 YR	1.0
FURNACE PRODUCTION	$6M x 0.7 AUTOMAT	4.2	$4M x 0.7	2.8
LABOR				
FLYER/PLATFORM BERTH/DESPATCH	INCLD IN RENDEZVOUS	–	0.8 x 33 x 20 MAN-HR x $3400	1.8
FURNACE OPERATIONS	2.5 x 2 x 20 MAN-HR x $3400	0.3	2.5 x 33 x 4 MAN-HR x $3400	1.1
COMPARATIVE TOTAL		66.9		32.2

MISSION INPUT DATA	NO.	MASS kg	POWER REQD KW	MATERIALS kg	USEFUL OUTPUT kg	PROCESS TIME DAYS
SINGLE FURNACE	1.0	900	7.0	339	–	11
FURNACES OPERATING	2.5	1120	17.5	848	–	–
FURNACE + ASE LAUNCHED	0.7	–	–	–	–	–

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V83-0165-384(T)

Fig. 3.2-30 Average Annual Costs for 10 Years of Bulk GaAs Production

liquid phase epitaxy is thought to benefit from low-g processing. Consequently, this important market and process have been selected for evaluation.

Market Analysis - Two forms of Ga-As are presently marketed, conductive and semi-insulating; applications are the same as for bulk Ga-As. Thin film Ga-As, grown on 375 to 750 μm thick Ga-As wafers, is used in the same applications. Thin film surface processing is usually done by liquid phase epitaxy (LPE), vapor phase epitaxy (VPE), or ion implantation. Only LPE will be treated as a low-g process.

Ga-As wafers are commercially supplied by abut a dozen companies. The companies with the largest market segments are the Galluim Arsenide Products division of MACOM, and Cominco America . The wafers are most frequently used as substrates for thin film processing operations. Thin film materials are supplied to manufacturers of the system or subsystem hardware for the previously listed applications. Prominent users are the makers of missiles, radar, communications, surveillance, laser and integrated circuit systems. Many of these companies do their own thin film processing (e.g., Hughes, Rockwell, Hewlett-Packard) whereas others purchase custom films or subassemblies.

The market for Ga-As has been discussed in the previous subsection, and the production in 1996 is scaled for 200 kg of thin films. It is anticipated that this market will expand to 600 kg by 2000. The anticipated selling price for this premium quality Ga-As final product is $600K/kg. The market is thus projected to be $360M in the year 2000.

Mission Description - The processing thin film Ga-As in space is predicated on an improved film deposit in the absence of gravitationally driven convection, during the liquid phase epitaxy (LPE) process. In addition, if a liquid phase electropitaxial (LPEE) process is used, the low-g environment will serve to damp the convection resulting from joule heating in the liquid. This may permit operation at current densities that are impossible terrestrially due to melt turbulence from the joule heating induced buoyancy convection.

The LPE or LPEE process for Ga-As involves exposure of a high quality Ga-As substrate to a doped gallium melt in the presence of a carefully controlled thermal environment such that a thin layer of new material is deposited on the surface of the substrate. The new layer duplicates the surface of the substrate; this is referred to as epitaxial growth. If a sequence of differing dopant layers is desired, perhaps in a periodic array, then the substrate is exposed to a sequence of liquid metal baths. This process is shown schematically in Fig. 3.2-31. If electroepitaxy is used, then there is the addition of electrical leads to the substrate and liquid metal bath and the epitaxial process is "boosted" by the presence of the electric field. This improves deposition rates, but adds complexity to the deposition process and control.

The equipment required is an LPE or LPEE furnace, resupply modules including substrates, a process control unit and data acquisition system.

Requirements - The unit requirements for this mission are summarized in the NASA Payload Element forms (Part IV). The significant time-phased requirements are given in Fig. 3.2-32 for the estimated annual productions.

Benefit Analysis - Alternatives and procedures are the same as discussed for Hg-Cd-Te in Subsection 3.2.2.2. Results are given in Fig. 3.2-33 and 3.2-34 and show a Space Station benefit of $17.6M per year. Labor costs are higher on the Space Station because the units are loaded/unloaded every three days instead of every six months As mentioned for Hg-Cd-Te, savings accrue from the reduced number of rendezvous and free flying platforms.

3.2.2.5 Production of Protein Crystals - The growth of protein crystals in space is attractive because of low-g benefit and very high product cast. The major uncertainty with this product is the timing of the market development.

Market Analysis - This is essentially an untapped market. That is, there is presently no commercial supplier of protein single crystals, though Brookhaven National Laboratory acts as a depository and archive for such crystals. This is suitable for some crystals; however, many others have a very limited shelf life and are unsuitable for further testing.

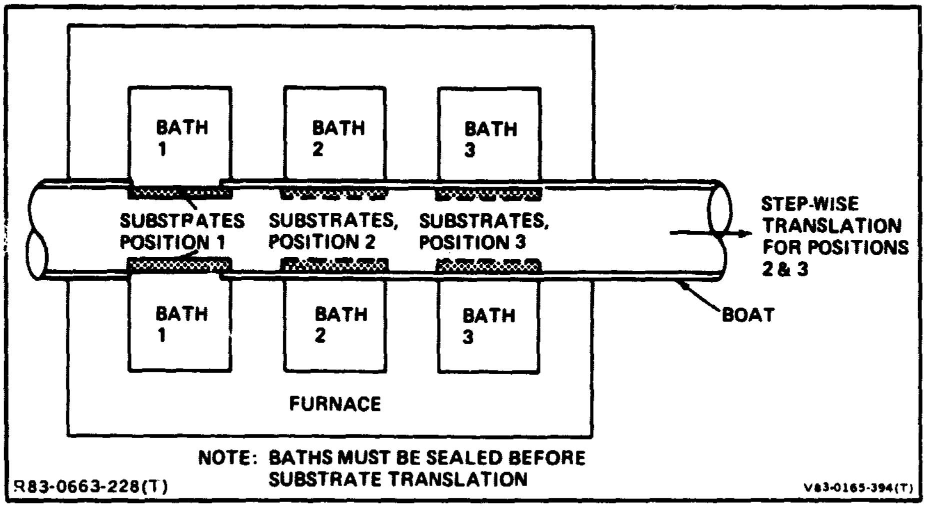

Fig. 3.2-31 Liquid Phase Epitaxy (LPE) Process

	'95	'96	'97	'98	'99	2000
UNITS TRANSPORTED, kg	–	1	1	0	1	0
UNIT MASS TRANSP, kg	–	700	700	0	700	0
UNITS OPERATING	–	1	2	2	3	3
MATERIALS TRANSPORTED, kg	–	1004	2008	2008	3012	3012
CREW TIME **, MAN-HR	–	1460	2920	2920	4380	4380
OPERATING POWER, kW	–	6.5	13.0	13.0	19.5	19.5
POWER DUTY CYCLE	–	0.83	0.83	0.83	0.83	0.83

**4 HR EVERY DAY PER UNIT

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Fig. 3.2-32 Commercial Production Schedule for Thin Film GaAs

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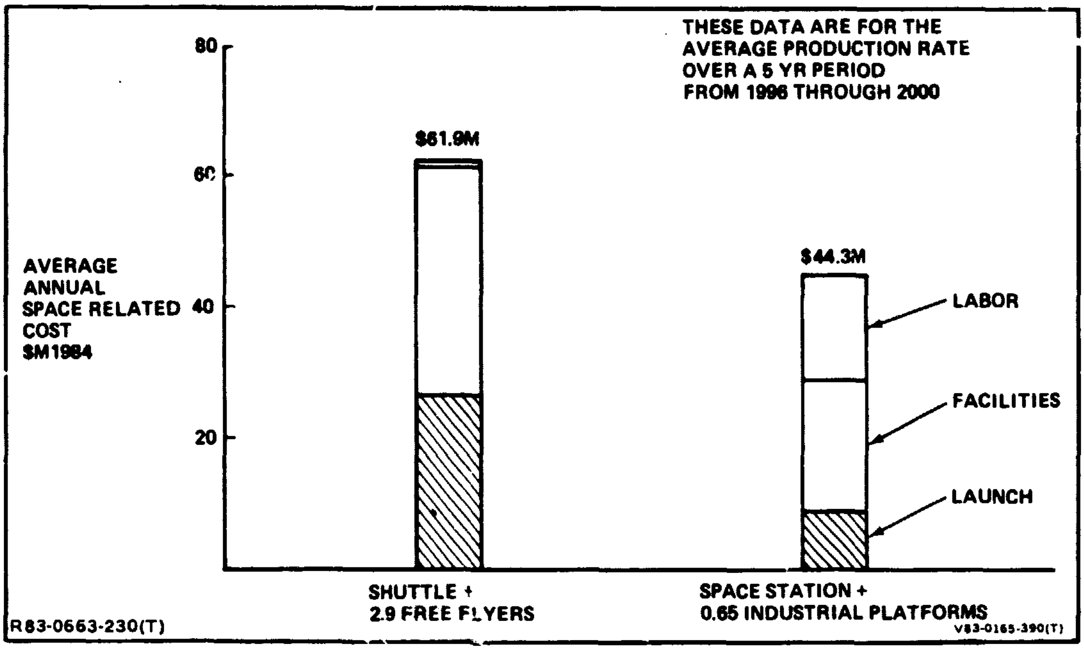

Fig. 3.2-33 Comparative Costs of Thin Film GaAs Production

	SHUTTLE + 5 KW FREE FLYER (2.9 REQD)	$M	SPACE STATION + 22 KW INDUST PLATFORM (0.65 REQD)	$M
LAUNCH				
MATERIALS	$2479/0.7 PER kg	7.8	$2479/0.9 PER kg	6.1
FURNACES + ASE	$2479/0.7 PER kg	5.1	$2479/0.9 PER kg	2.3
RENDEZVOUS	2.9 x 2/YR x $0.88M	5.1	0.09 x $0.88M	0.1
LOITER	2.9 x 2/YR x 2d x $0.66M	7.7		–
FACILITY				
SHARE OF FLYER/PLATFORM	2.9 x $200M/20 YR	29.0	.65 X $500M/20 YR	16.3
FURNACE DEVELOPMENT	$40M/20 YR HIGHLY	2.0	$20M/20 YR	1.0
FURNACE PRODUCTION	$8M x .6 AUTOMAT	4.8	$4M x 0.6	2.4
LABOR				
FLYER/PLATFORM BERTH/DESPATCH	INCLD IN RENDEZVOUS	–	0.65 x 120 x 20 MAN-HR x $3400	5.3
FURNACE OPERATIONS	2.9 x 2 x 20 MAN-HR x $3400	0.4	2.2 x 120 x 12 MAN-HR x $3400	10.8
COMPARATIVE TOTAL		61.9		44.3

MISSION INPUT DATA	NO.	MASS kg	POWER REQD KW	MATERIALS kg	USEFUL OUTPUT kg	RESUPPLY INTERVAL DAYS
SINGLE FURNACE	1	700	6.5	200	–	3
FURNACES OPERATING	2.2	–	14.3	2209	–	–
FURNACE + ASE LAUNCHED	0.6	840	–	–	–	–

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Fig. 3.2-34 Average Annual Costs for 5 Years of Thin Film GaAs Production

As a result of the absence of a supplier, each user organization must grow its own crystals. This involves repetitive climbing of the learning curve at numerous locations, and great duplication of effort.

Many universities, institutions and commercial laboratories, contacted as part of our Space Station constituency development activity, expressed a strong preference to purchase needed crystals, if they were available in a reasonable time frame and at a reasonable cost.

Presently three to nine months are typically "invested" to grow an adequate set of crystals. This sizable investment in manpower would be eliminated if crystals were available at from \$500 to \$1500 a piece. On a unit weight basis, this would equate to about \$1000M/kg of crystal.

Obviously, the protein crystals qualify on the basis of selling price, and the real question is whether the market is deep enough to offset the on-orbit and transportation charges. Initial production is aimed at 1300 crystals/year, increasing to 10,000/year as the market develops. At \$1000/crystal, the market will be approximately \$10M in the year 2000.

Mission Description - The reason for growing protein crystals in space is that the low-g environment will allow the crystals to be grown under diffusion-controlled conditions. This is important from a number of standpoints, including: the absence of sedimentation, which stagnates crystal growth; the absence of turbulence, which improves the survival of the growing crystals (fragility consideration); and a more regular transport of solute to the growing crystal.

The crystal growth process is shown schematically in Fig. 3.2-35. There are three baths, separated by permeable membranes, housed in an isothermal furnace or bath. Two cases should be considered. The first case has the same solution in Baths No. 1 and No. 2; the species that diffuse from these baths through the permeable membrane react with the solution in bath No. 3 resulting in crystallization. The second case has differing solutions in baths No. 1 and No. 2. Differing species diffuse through the permeable membranes and into bath No. 3, which

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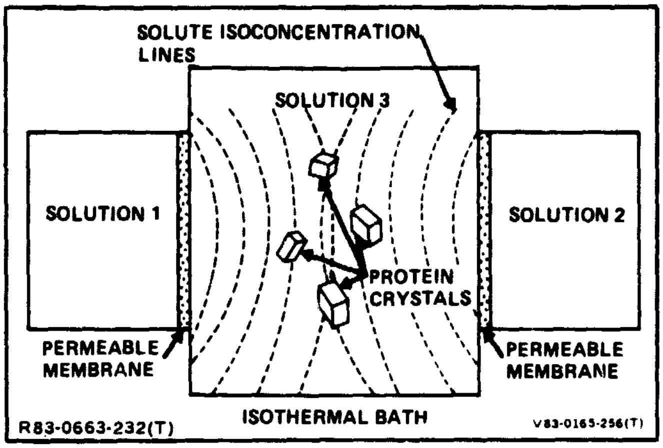

Fig. 3.2-35 Protein Crystal Growth Process

serves as a transport medium. Crystallization occurs when the opposing diffusion fronts overlap and the diffusing species react.

Mission Requirements - The critical elements for this production payload are continuous low-g, continuous power, and continuous heat rejection. The equipment needed is a modified Jakobi crystal growth reactor, an isothermal furnace or bath, a power supply or conditioner, a process control unit, cooling loop and heat rejection system, data acquisition system and film or videotape record. The critical requirements are tabulated in the attached data sheets. Crew operations would be similar to those requiring refurbishment, resupply, management and data consolidation (previously discussed for other production payloads).

The data needed are temperatures, PH, time and perhaps a film record (time lapse, not continuous). Growth periods will vary from a week to a month, depending on the crystal being grown. Data requirements will fall between 1 and 10 M bit.

The unit requirements for this mission are summarized in the NASA Payload Element Data Sheets, Part IV of this volume. The significant time-phased requirements are given in Fig. 3.2-36 for the estimated annual productions.

Benefit Analysis - Alternatives and procedures are the same as discussed for Hg-Cd-Te in Subsection 3.2.2.2. Results are given in Fig. 3.2-37 and 3.2-38, and show a Space Station benefit of $13.3M per year. Comments are the same as for the previous missions.

	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
REACTORS TRANSPORTED	–	1	1	1	1	1	2*	1*	2*	2*
REACTOR MASS TRANSP, kg	–	300	300	300	300	300	600	300	600	600
REACTORS OPERATING	–	1	2	3	4	5	6	6	7	8
MATERIALS TRANSPORTED, kg	–	86.9	174	261	348	435	521	521	608	695
CREW TIME**, MAN-HR	–	139	278	417	556	695	834	834	973	1112
OPERATING POWER, kW	–	1.0	2	3	4	5	6	6	7	8
POWER DUTY CYCLE	–	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

* INCLUDES REPLACEMENT OF EQUIPMENT 5 YEARS OLD
**8 HR EVERY 21 DAYS PER REACTOR

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Fig. 3.2-36 Commercial Produc ion Schedule for Protein Crystals

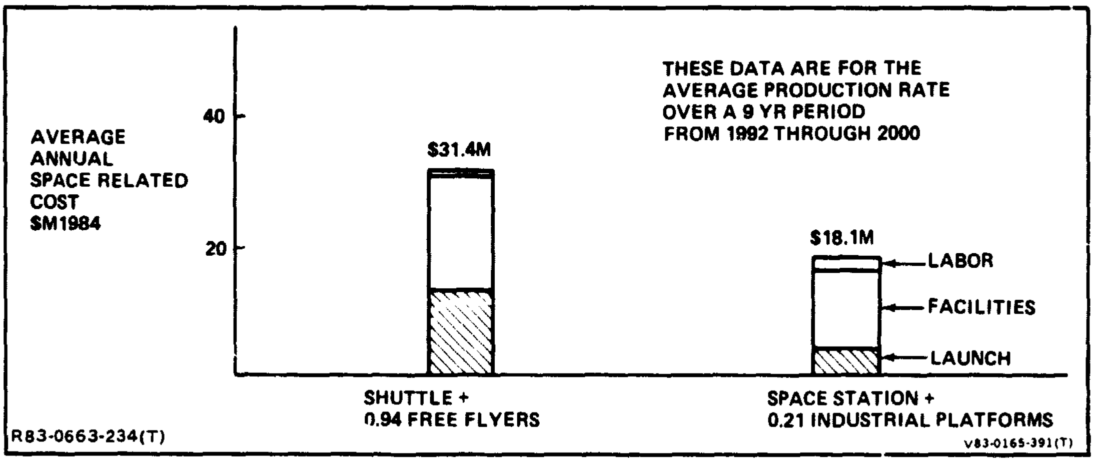

Fig. 3.2-37 Comparative Costs of Protein Crystal Production

	SHUTTLE + 5 KW FREE FLYER (0.94 REQD)	$M	SPACE STATION + 22 KW INDUST PLATFORM (0.21 REQD)	$M
LAUNCH				
MATERIALS	$2479/0.7 PER kg	1.4	$2479/0.9 PER kg	1.1
REACTORS + ASE	$2479/0.7 PER kg	7.8	$2479/0.9 PER kg	3.0
RENDEZVOUS	0.94 x 2/YR x $0.88M	1.7	0.06 x $0.88M	0.0
LOITER	0.94 x 2/YR x 2d x $0.66M	2.5		–
FACILITY				
SHARE OF FLYER/PLATFORM	0.94 x $200M/20 YR	9.4	0.21 x $500M/20 YR	5.3
REACTOR DEVELOPMENT	$25M/20 YR	1.3	$20M/20 YR	1.0
REACTOR PRODUCTION	$5M x 1.33	6.7	$4M x 1.33	5.3
LABOR				
FLYER/PLATFORM BERTH/DESPATCH	INCLD IN RENDEZVOUS	–	0.21 x 17 x 20 MAN-HR x $3400	0.2
REACTOR OPERATIONS	4.7 x 2 x 20 MAN-HR x $3400	0.6	4.7 x 17 x 8 MAN-HR x $3400	2.2
COMPARATIVE TOTAL		21.4		18.1

MISSION INPUT DATA	NO.	MASS kg	POWER REQD KW	MATERIALS kg	USEFUL OUTPUT kg	PROCESS TIME DAYS
SINGLE REACTOR	1	300	1	87	–	21
REACTORS OPERATING	4.7	–	4.7	406	–	–
REACTORS + ASE LAUNCHED	1.33	1100	–	–	–	–

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Fig. 3.2-38 Average Annual Costs for 9 Years of Protein Crystal Production

3.2.2.6 Isoenzyme Separations - There are many pharmacological substances such as enzymes, isoenzymes, hormones, etc, which are difficult to isolate from similar substances with sufficient resolution to provide significant quantities for medical use. For many substances with similar electrophoretic mobilities, the most successful ground-based technique for isolation is conventional small pore gel electrophoresis. However, these separations generally do not provide sufficient resolution with large scale yield of the desired product. In zero g, using large pore gels which cannot be maintained in 1g, increased resolving power of the separation while maintaining low ohms heating and low electrical potential, is expected to provide reasonable yields of high specificity product. The process is illustrated schematically in Fig. 3.2-39.

A typical example of an electrophoretic separations commercial mission is the Large Pore Gel Electrophoretic Separation of Isoenzymes (antigens) used for the production of medical diagnostic kits. The overall production cycle is outlined in Fig. 3.2-35.

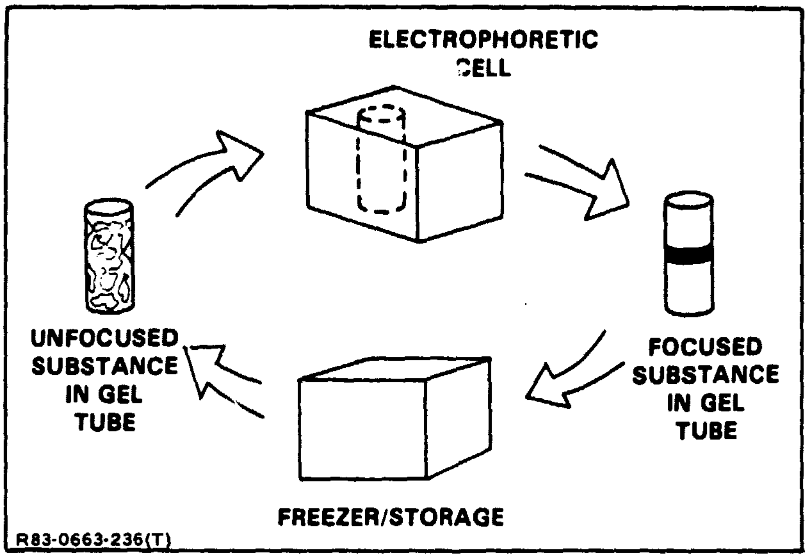

Fig. 3.2-39 Separation of Isoenzymes by Large Pore Gel Electrophoresis

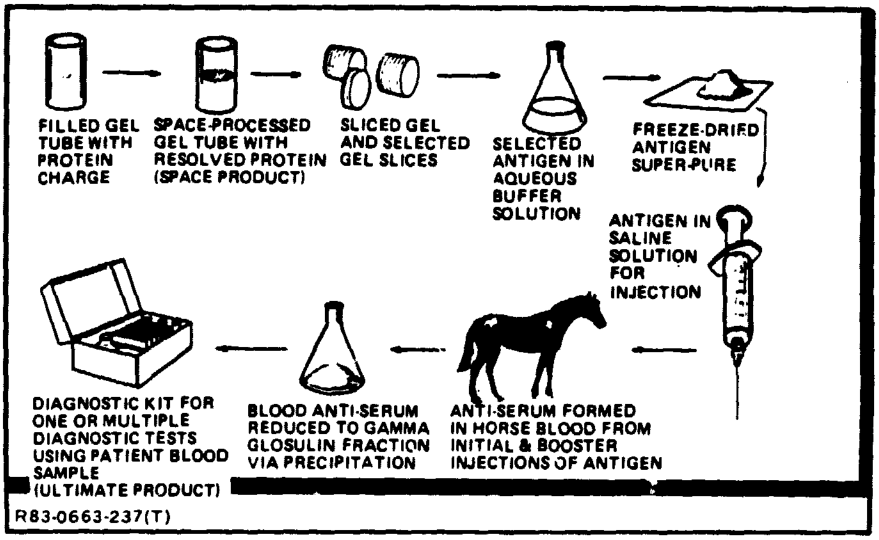

Fig. 3.2-40 Isoenzymes Overall Processing Cycle

Market Analysis - The production of isoenzymes in space would open up a market for diagnostic kits that could be used by physicians and clinics. The kit would contain antibodies, which are produced by the isoenzymes, to permit the diagnosis of many diseases. Isoenzymes of most immediate interest would be substances such as glycogen phosphorylase and creative kinase.

The isoenzymes separation system envisioned for Space Station would be flown in three phases: pilot plant; small scale production; and full scale production. At the start of full scale production, annual sales of 5 million kits are assumed. Based

on market data developed in the BUS study (Reference 12), the price per kit would be $16.50 (in 1984 dollars). Annual market potential is as follows:

- **Pilot plant** - 1.25 million kits at $20.6M sales
  - **Small-scale production** - 2.5 million kits at $41.25M sales
- **Full-scale production** - 5 million kits at $82.5M sales, increasing to 12.5 million kits at $206M sales by the year 2000.

Those data are summarized in Fig. 3.2-41.

	PILOT PLANT	SMALL SCALE PRODUCTION	FULL SCALE PRODUCTION 1994	FULL SCALE PRODUCTION 2000
SALES	$ 20.6 M	$ 41.25 M	$ 82.5 M	$ 206 M
MISSION* AND GROUND MANUFACTURING COSTS	$ 7.0 M	$ 14.0 M	$ 27.9 M	$ 70.0 M
OTHER COSTS (SALES, ADMINISTRATION, ETC.)	$ 6.5 M	$ 12.5 M	$ 25.0 M	$ 62.5 M
POTENTIAL PROFIT	$ 7.1 M	$ 14.75 M	$ 29.6 M	$ 73.5 M

* NOT INCLUDING SPACE STATION USAGE

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Fig. 3.2-41 Isoenzyme Production Annual Market Value

Mission Description - The objective of the mission is to provide a facility with sufficient resolution and throughput for the commercial production of isoenzymes. The Space Station provides a shirt sleeve environment where the operator loads raw material, monitors the processing and removes the products on a daily basis.

Initially, shuttle sortie missions will be required to verify the concept of large pore gel electroporesis in space for the separation of isoenzymes. During the early phase of Space Station, pilot plant studies will demonstrate the capability to produce isoenzymes in commercial quantities. Production facilities will then be developed for the manufacturing of isoenzymes in space. The production level will be increased with full-scale production by 1994. As shown in Fig. 3.2-42, the typical six-month in-space production cycle will consist of five monthly processing periods and one month for maintenance (if required).

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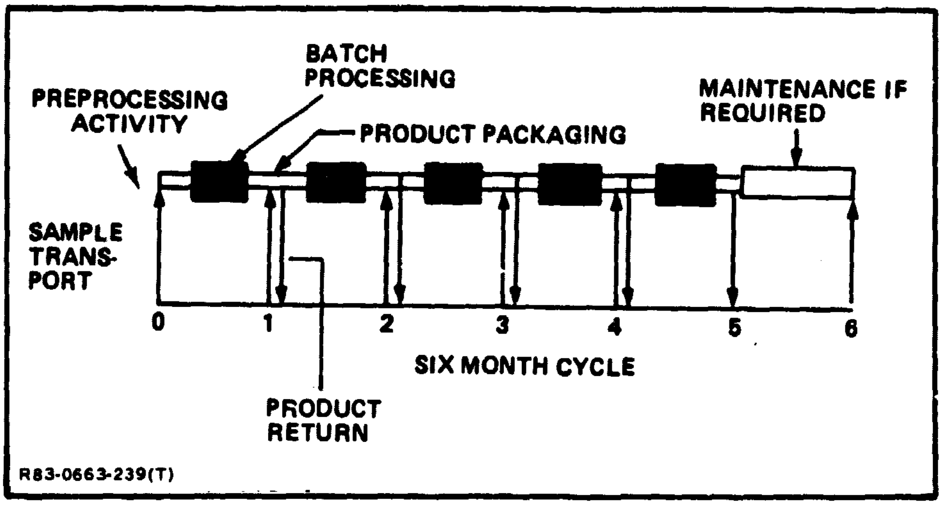

Fig. 3.2-42 Typical Six-Month In-Space Production Cycle

Requirements - The isoenzyme production equipment consists of rack-mounted batch electrophoresis separators and support equipment (freezer, transfer containers). Each unit with its support equipment has a mass of 200 kg and a volume of 0.5 m^3. Power required is 375 W/unit; raw material supply and product return is 36 kg/unit/year; maximum storage life of raw material and product is six months; maximum g-levels allowable are 10^{-2} to 10^{-3} g.

Pilot plant production in 1991 would involve one separation unit; small scale production in 1992/3 would utilize two units. Full-scale production would begin with four units in 1994 and increase to 10 units by the year 2000.

The significant time-phased requirements are given in the schedule, Fig. 3.2-43, for the estimated annual productions. Other requirements are given in the NASA Payload Element Data Sheets, Part IV of this volume.

Benefit Analysis - Alternative mission implementation using a free flying platform would require automated equipment and increased storage capability. Development and servicing via the STS would be required. Mission implementation using Spacelab/STS in the sortie mode would involve multiple Spacelab flights. A comparison of implementation costs for initial full-scale production is given in Fig. 3.2-44. The computations are summarized in Fig. 3.2-45.

	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
PRODUCTION PHASE	←PILOT→		SMALL SCALE		← FULL SCALE →						
APPARATUS TRANSPORTED		1	2	0	4	0	2	0	6*	0	4*
APPARATUS MASS TRANSP, kg		200	400	0	800	0	400	0	1200	0	800
APPARATUS OPERATING		1	2	2	4	4	6	6	8	8	10
MATERIALS TRANSPORTED, kg		18	72	36	144	144	216	216	288	288	360
CREW TIME **, MAN-HR		55	110	55	220	220	330	330	440	440	550
OPERATING POWER, kW		0.4	0.8	0.8	1.5	1.5	2.25	2.25	3.0	3.0	3.75
POWER DUTY CYCLE		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

**0.15 HR EVERY DAY PER APPARATUS

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Fig. 3.2-43 Commercial Production Schedule for Isoenzyme Separations

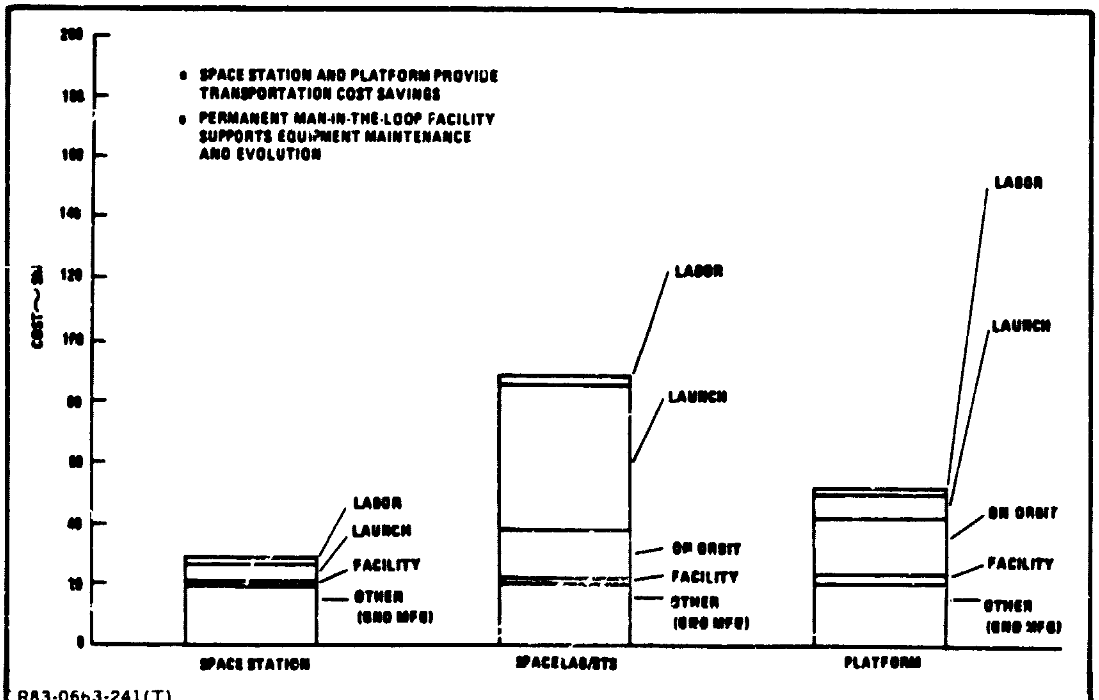

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Fig. 3.2-44 Isoenzyme Separations Mission Comparison

Space Station mission implementation costs are lower than those for Spacelab/STS platform missions. Spacelab/STS mission implementation costs are higher due to the greater launch costs associated with multiple shuttle sortie flights. Platform mission implementation costs are higher due to the greater on-orbit costs associated with platform use and STS revisits.

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COST CATEGORY		SPACE STATION		SPACELAB/STS		PLATFORM	
Labor	Space Tech. ($10.2M/Man Yr)	2.5 Man Wks.	$0.5M	2.5 Man Wks.	$0.5M	1 Man Wk.	$0.2M
	Ground Crew ($1500/Man Wk)	*	-	*	-	*	-
Launch	Payload Launch Logistics Support ($84.3M/Launch)	6.7% x 1 0% x 9	$5.63M $0M	6.7% x 10 N/A	$56.0M -	10% x 1 0% x 3	$8.43M $0M
	Rendezvous Cost ($0.88M Ea.)	6.7% x 1 + 0% x 9	$0.07M	N/A	-	10% x 4	$0.35M
On Orbit	Loiter Days ($0.66M Ea.)	N/A	-	N/A	-	3 x 4	$7.9M
	Standard EVA ($20K Ea. Sp Sta) ($200K Ea. STS)	N/A	-	N/A	-	12	$2.4M
	Platform Ops** ($100M/Year)					10%	$10M
	Spacelab Flight ($10M Ea.)	N/A	-	6.7% x 10	$6.7M	N/A	-
Facility	DDT&E + Production	Apparatus	$1.5M	Apparatus	$1.5M	Apparatus (Automated)	$13M
	OPS Support (15% DDT&EEP)		$0.22M		$0.22M		$0.45M
Other	Ground Manufacturing		$20M		$20M		$20M
	TOTAL COSTS	$27.92		$34.92		$52.64M	

* INCLUDED IN GROUND MANUFACTURING
**INCLUDES POCC AND TDRSS COSTS

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Fig. 3.2-45 Isoenzyme Separations Cost Comparison

The market values of pilot plant, small-scale production, and full-scale production are summarized in Fig. 3.2-41. Mission/Ground manufacturing costs for 1994 are calculated in Fig. 3.2-45 and are scaled to production rate in the other columns. Other costs are based on Beneficial Uses of Space study data, again scaled to production rate, and 1984 dollars.

3.2.2.7 **Production of Biologicals** - This area of space-based experimentation is described in the following paragraphs.

Market Analysis - The market for biological products that potentially could benefit from processing in microgravity is very significant. These products include not only diagnostic substances but also therapeutic ones, such as urokinase (produced from kidney cells and used in the treatment of blood clots), somatotroph (used to treat growth hormone deficiencies), and Beta cells (used in the treatment of diabetes). Diabetes, for instance, is a common chronic disease affecting millions of people worldwide. In the United States alone, approximately 5 million people are

afflicted with this disease. Over $12 billion is spent in the U.S. for the treatment of diabetes, including drug therapy (primarily the administration of insulin), hospital care, home care, laboratory evaluations and health education. It is estimated, considering this spectrum of health care activities, that the full-scale production and administration of Beta cells for treatment of a large portion of the diabetic population would be a multi-hundred-million-dollar industry, worldwide. Recent advances in the growth of Beta cells in cultures look promising; however, the problem of rejection by the body needs to be solved, possibly through improved purity of the cells. Continued advances in the production of urokinase and somatotroph also promise to be translated into more available, improved products to the users.

Our discussions with researchers in Wyeth Laboratories and GE Corporate Research and Development helped to place the spaceborne electrophoretic separations within the context of recent and projected developments in this rapidly advancing scientific/industrial field. It was pointed out that there are several new bioprocessing techniques for the production of pharmaceuticals which would compete with electrophoresis. Notable among these techniques are DNA Splicing, Fluorescence Activated Cell Sorting (FACS) and Monodonal Antibodies (MAbs). The latter, for instance, only represented a market of $15 million in 1982, but is estimated to grow to $5 billion by 1992. If spaceborne electrophoresis is proven to yield a superior product or a less expensive one, it could capture a large portion of that market, within the time-frame of the Space Station. Additional laboratory and space research is needed to identify and assess this portion of the market in selected areas where continuous flow electrophoresis is applicable. The specific characteristics of separations in microgravity and their performance and cost advantage over other competing techniques will thus be determined. Most of this space experimentation will be possible on-board Spacelab, prior to potential large-scale production in the Space Station time-frame.

For planning purposes, we have estimated that the initial phases of full-scale production in space will produce relatively modest amounts of biologicals, in the order of 120 kg undiluted yield per year. These are based on producing biologicals with high economic leverage where minute amounts of the substance will be used in each diagnostic or therapeutic kit.

Mission Description - The basic production process is illustrated schematically in Fig. 3.2-46. The principal characteristic of the space environment that is used

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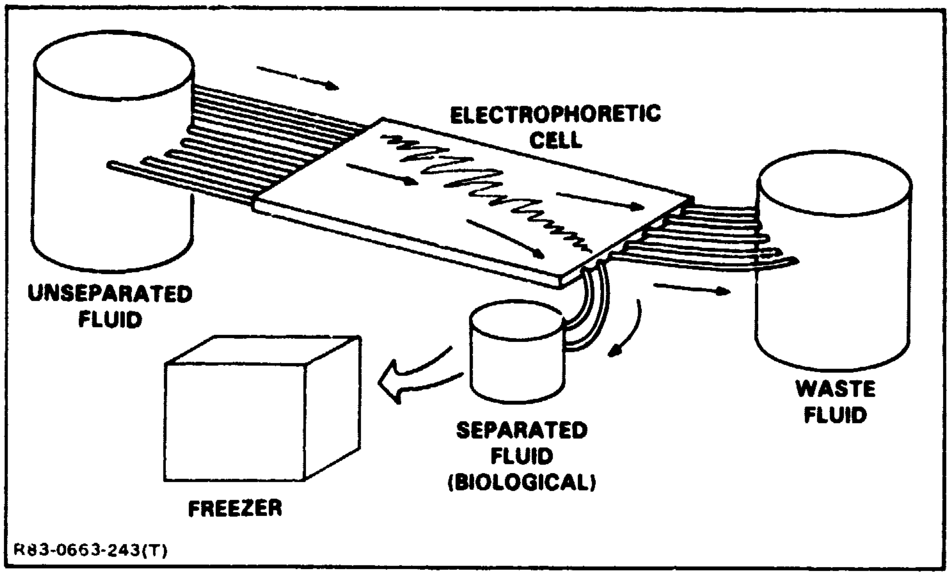

Fig. 3.2-46 Production of Biologicals by Continuous Flow Electrophoresis

in this mission is reduced gravity, which lessens thermally and solutally driven convection. The continuous flow electrophoresis process consists of performing separations (or purification) of biologicals by exploiting the variation in mobility of its constituents (e.g., pure biological impurities) due to the application of an electric field across the cell containing the biological. Since the precision and resolution of these separations depend on the unperturbed deflection of the flow due to its susceptibility to the electric field, it is important to minimize the disturbing effects of thermally and solutally driven convection. In a microgravity environment in space, the thermally driven convection becomes negligible and, therefore, the electrophoretic separations will potentially be significantly improved. In addition, in low-g, the concentration of the solution can be increased without introducing convection, thus improving throughput.

The equipment required to perform this mission will consist of the electrophoretic separation cell, fluid storage vessels and auxiliary operation and control apparatus. Figure 3.2-47 shows a typical conceptual arrangement for the incorporation of the equipment within a pressurized module that permits operation. There are three equipment racks (patterned after those used by Spacelab). The center rack houses the electrophoretic cell, electronic controls for astronaut interface, and the separation-fraction collection vessels. The rack on the left carries a microprocessor (for process control and safety data management), a freezer and buffer fluid storage, while the third rack contains the unprocessed

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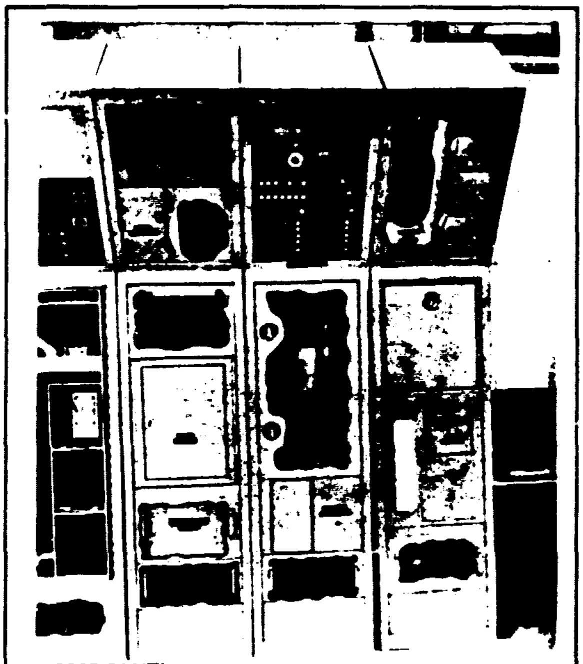
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Fig. 3.2-47 Biologicals Production Facility

biologicals, a centrifuge (if required in some of the processes) and the thermal control system for the unit.

The role of the crew in this mission would be the loading and unloading of biologicals during the logistic cycles, control and monitoring of the biological separation cycles, maintenance/repair and modification of the process parameters if the conditions warrant it. In full production, a dedicated technician could be devoted to this mission during a 10 to 12 hour period per day with automated sequences being scheduled during non-attended hours of the day. A typical production run would be 24 hours in duration.

Requirements - Crew involvement in this mission will require a technician who is thoroughly trained in the operation and maintenance of the electrophoretic apparatus. Although a scientist is not needed for the mission, the technician should be well versed in the biological aspects of the separations that are to be performed.

The nominal weight of the mission equipment is approximately 410 kg. Every three years the equipment is replaced or refurbished as a maintenance procedure, to expand its capabilities (as required) and take advantage of improvements that

are made possible by the intervening technological advance. The average operating power requirement is 700 watts, and standby power is approximately 250 watts.

The nominal logistics cycle for delivery of new material and return of products is 30 days. The new material transported up is 250 kg of dilute unseparated fluid per cycle, or 3000 kg per year. The products transported down are 100 kg of dilute biological material plus 150 kg of waste per cycle, or 1200 kg and 1800 kg respectively per year. The 1200 kg of dilute biologicals is subsequently concentrated to 120 kg of undiluted product on the ground. The significant time-phased requirements are given in Fig. 3.2-48 for the estimated annual productions. Other requirements are given in the Payload Element Data Sheets, Part IV of this volume.

	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
APPARATUS TRANSPORTED	1	0	0	1*	0	0	1*	0	0	1*	0
APPARATUS MASS TRANSP, kg	410	0	0	410	0	0	410	0	0	410	0
APPARATUS OPERATING	1	1	1	1	1	1	1	1	1	1	1
MATERIALS TRANSPORTED, kg	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
CREW TIME **, MAN-HR	1095	1095	1095	1095	1095	1095	1095	1095	1095	1095	1095
OPERATING POWER, kW	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
POWER DUTY CYCLE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* REPLACEMENT
**12 HR PER DAY PER APPARATUS

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Fig. 3.2-48 Commercial Production Schedule for Biologicals

Benefit Analysis - The estimate of the value of space-produced biologicals will require two intermediate steps (in accordance with the previous discussion under Market Analysis): (1) laboratory and space experimentation and analysis to obtain a better scientific understanding of the characteristics of electrophoretic separations of various classes of biological substance; and (2) a detailed comparison of the improved properties of these separations with the products that are possible and those that are projected using new processing techniques such as DNA Splicing, Fluorescence Activated Cell Sorting (FACS), and Monodonal Antibodies (MAbs). Once the unique products that show an advantage from space processing have been identified, the actual benefits can be easily assessed.

A comparison of the costs associated with three different implementation techniques is shown in Fig. 3.2-49; the computations are summarized in Fig. 3.2-50.

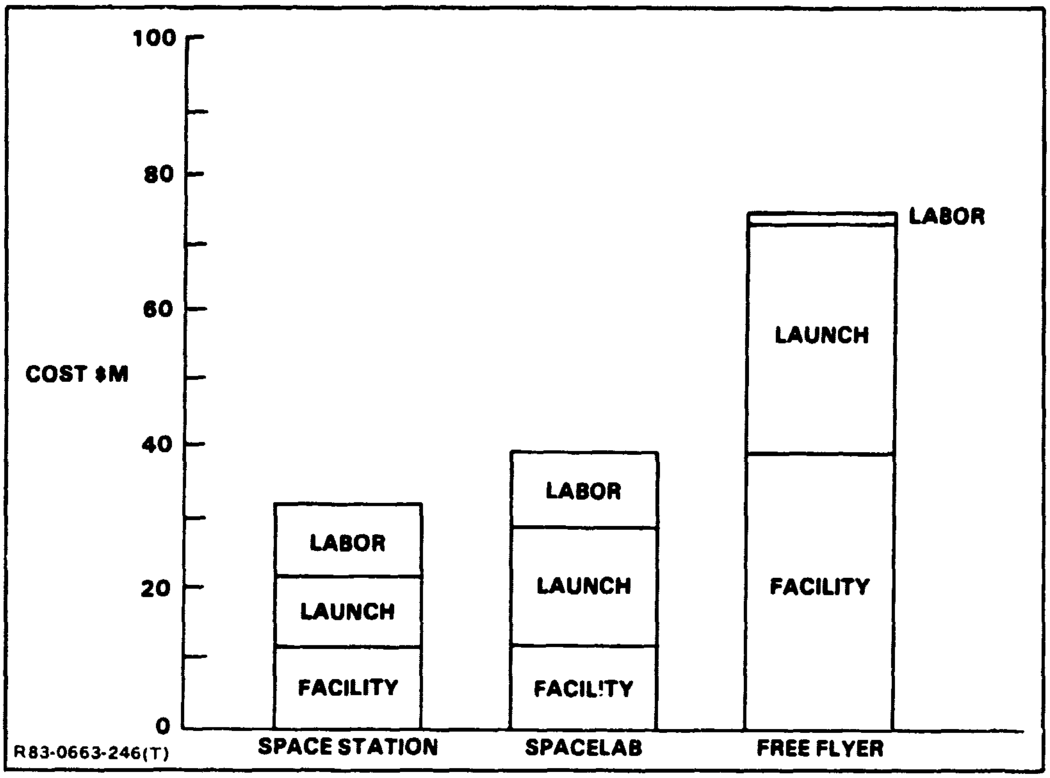

Fig. 3.2-49 Commercial Production of Biologicals Mission Comparison (Annual Cycle)

COST CATEGORY		SPACE STATION		SPACELAB/STS		DEDICATED FREE FLYER	
LABOR:	TECHNICIAN ($10.2 M/MAN YR)	1 MAN	10.2 M	1 MAN	10.2 M	1 MAN WK	0.2 M
	GROUND CREW ($1500/MAN WK)	2 MEN	0.2 M	2 MEN	0.2 M	4	0.3 M
LAUNCH:	PAYLOAD ($84.3 M/LAUNCH)	0.1 SHUTTLE P/L	8.4 M	0.1 SHUTTLE P/L X 6 LAUNCHES	17.2 M	0.5 SHUTTLE P/L	14.0 M
	RENDEZVOUS COST ($0.88 M EACH)	3 REND.	0.9 M	N/A	–	12 REND./YR	10.6 M
ON ORBIT:	LOITERING ($0.66 M EACH)	N/A	–	N/A	–	12 CYCLES	7.9 M
EQUIPMENT DDT & E		SEMI AUTO	11.7 M	SEMI AUTO	11.7 M	AUTOMATED	17.9 M
SPACECRAFT DDT & E						DEDICATED	23.3 M
TOTAL COST			31.4 M		39.3 M		74.2 M
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Fig. 3.2-50 Commercial Production of Biologicals Cost Comparison (Annual Cycle)

The results show that the cost of performing this mission can be reduced by approximately 20% by using the Space Station, compared with Spacelab. The cost of implementing the mission is almost doubled by using a dedicated free flyer.

3.2.2.8 X-Ray Target Production - The technical and commercial prospects for a business venture based on the preparation of tungsten X-ray tube targets with improved service properties in a space-based microgravity facility has been reexamined. Such a possibility was studied in the earlier General Electric Beneficial Uses of Space (BUS) investigations where it was selected as one of four example processes in the Phase III Final Report (November 30, 1975). Recent visits to the GE Medical Systems Division, where X-ray tubes are manufactured, and to the Corporate Research and Development Center, which does basic metallurgical research to support this work, indicate that improvements made possible by the exploitation of the microgravity environment are still of interest. The earlier ideas of forming tungsten of improved crystal structure by undercooled solidification have now been extended to include possibilities for vapor deposition from molten tungsten levitated at high superheat in the microgravity environment.

A significant amount of work has been done in the terrestrial laboratory at GE using electromagnetic levitation techniques to suspend molten tungsten in a vacuum. The production of 1 cm single crystals by allowing the suspended material to solidify by radiative cooling after cessation of electron beam melting has been reported in the literature, but practical yields cannot be achieved because of levitation instabilities that occur because of the high tungsten density and outgassing at the high melting temperature. It is believed that practicable single crystal production rates could be achieved by levitation in a microgravity environment. This environment would also allow possible production of fine-grained or vapor-deposited material by achieving larger undercoolings or higher superheats than possible terrestrially. Present limitations in X-ray target segments are believed largely associated with the necessity of using powder metallurgy techniques with the associated contamination and poor intergranular bonding.

Market Analysis - The detailed market forecast carried out in the BUS study is still assumed valid. This shows a world demand for 160,000 X-ray target segments by the year 1992. A new requirement for target technology is the ability to survive the higher power densities associated with Computer Aided Tomography (CAT) applications. Success in achieving a long-life X-ray tube which provided the

needed high resolution could form the basis for a reasonable assumption of a 50% world market penetration with a target selling price of $500. The projected annual market is shown in Fig. 3.2-51. It should be mentioned that GE is the sole U.S. manufacturer of X-ray targets, which has led to regulation of this business.

SALES	$40.0 M
MISSION COSTS	23.0 M
OTHER COSTS (GROUND MANUFACTURING, ETC.)	8.0 M
POTENTIAL PROFIT	9.0 M

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Fig. 3.2-51 X-Ray Target Production Annual Market Value

Mission Description - Two processes are available for yielding tungsten of potentially better metallurgical properties than the present powder metallurgy product: undercooled solidification; or vapor deposition on a molybdenum substrate by superheating the melt. The latter possibility is particularly attractive because of the minimization of tungsten scrap and post-processing machining costs, as well as the possibility of using thinner tungsten layers.

The vapor deposition X-ray target production process is summarized in Fig. 3.2-52. Materials prepared on the ground include tungsten spheres that serve as sources during the in-space vapor deposition process and molybdenum substrates that receive a coating of high purity tungsten. After in-space processing, the high purity tungsten target segments are machined and bonded to molybdenum target wheels, which are subsequently incorporated within large vacuum tubes that produce X-rays in medical and industrial applications. A typical target wheel is roughly 3 in. in diameter and has a tungsten target area that forms a $\frac{1}{2}$-in. ring near the circumference of one of its faces.

A pure tungsten layer of at least 6 mils is needed for most X-ray targets. This would typically require 20 min to build up using the vacuum vapor deposition

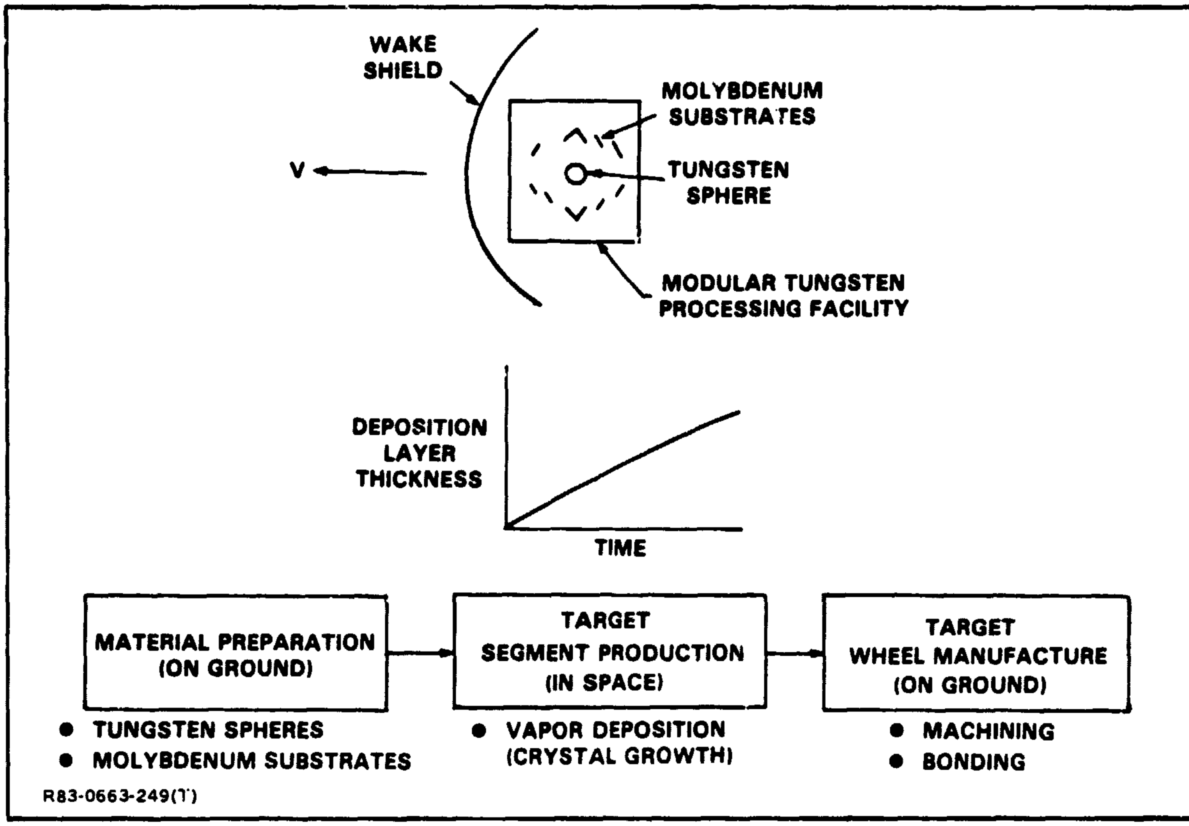

Fig. 3.2-52 Tungsten X-Ray Target Production Process

process. Processing sufficient target segments to build 80,000 targets per year requires 12 hr/day of active production. This could be accomplished with two 8-hr cycles per day, each consisting of 6 hr of active production and 2 hr of loading, unloading, start up and shut down.

Requirements - The required spaceborne equipment has been described in the BUS final report, Book 3. Figure 3.2-53, taken from that report, shows a description and weight breakdown by equipment components for processing of 1- and 5-cm diameter tungsten spheres. We have found that the economics of the vapor deposition process appears more favorable for spheres of 1.84-cm dia; nevertheless, we have doubled the estimated weight for the space production facility to 1500 kg in order to provide a more conservative design which exploits the much greater in-orbit residence time made possible by the Space Station. With the addition of 500 kg for a wake shield, total weight launched to orbit is 2000 kg.

Aside from onboard microprocessing of data for process control, a once per day data dump to earth consisting mainly of 1 Mbit of specimen image information

	EXPERIMENT VERSION (1 CM DIAMETER SPECIMENS)		PRODUCTION VERSION (5 CM DIAMETER SPECIMENS)	
	LB.	KG	LB	KG
CHAMBER & STRUCTURE	(143)	65	(143)	65
SAMPLE/CHARGE HANDLING	(145)	65.9	(300)	136.4
GATE VALVES	(94)	42.7	(94)	42.7
VENTING SYSTEM	(10)	4.5	(10)	4.5
GAS SUPPLY & PLUMBING	(20)	9.1	(10)	9.1
ION GAUGE & CONTROL	(20)	9.1	(20)	9.1
PROCESS CONTROLLER AND ELECTRONICS	(58)	26.4	(100)	45.5
ELECTRON BEAM GUN & POWER SUPPLY	(65)	29.5	(100)	45.5
ELECTRON BEAM POWER CONDITIONER	(100)	45.5	(150)	68.5
OPTICAL PYROMETER	(25)	11.4	(25)	11.4
MASS SPECTROMETER	(12)	5.4	(12)	5.4
CAMERA & LAMP	(13)	5.9	-	-
TV MONITOR	-	-	(15)	6.8
PROCESS RECORDER	(8)	3.6	(8)	3.6
RF POSITIONING COIL UNIT	(7)	3.2	(20)	9.1
COIL COOLING SYSTEM	(50)	22.7	(100)	45.4
RF POWER CONDITIONER	(30)	13.6	(100)	45.5
CABLING AND TERMINALS	(10)	4.5	(20)	9.1
	(810)	368	(1237)	561.9
VACUUM SYSTEM SUPPORT	(250)	113.6	(250)	113.6
10% CONTINGENCY	(106)	48.2	(149)	67.6
TOTAL	(1166)	529.8	(1636)	743.1

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Fig. 3.2-53 Modular Tungsten Processing Facility Equipment

should be provided. In the initial phases of operation, a single astronaut/technician would devote 8 hr/day to supervising the automated facility operation, loading and unloading it, and insuring safety of operation. Later, required manned attendance could be considerably reduced. Monthly maintenance and logistics activities would require 16 manhours. A total of 2220 kg/year of tungsten, molybdenum substrate and shipping containers would be brought up from earth and returned. Processed material should be returned to earth at least once per month. About 120 kg of expendable inert gas per year would also be required. These requirements have been summarized in the Payload Element Data Sheets, Part IV of this volume. At this time it is believed that a single facility would have an in-orbit useful lifetime of approximately three years, limited by obsolescence. The most significant facility requirement is perhaps the rather large in-orbit power requirement, which can be reduced to 15 kW as compared with as much as 50 kW by use of a smaller specimen (1.84 cm) at 200° superheat. The significant time-phased requirements are given in Fig. 3.2-54 for the estimated annual productions.

	'92	'93	'94	'95	'96	'97	'98	'99	2000
PRODUCTION PHASE		←PILOT PLANT→				← FULL SCALE →			
FACILITIES TRANSPORTED	–	1	0	0	–	1	0	0	0
FACILITY MASS TRANSP, kg	–	2000	0	0	–	2000	0	0	0
FACILITIES OPERATING	–	1	1	1	–	1	1	1	1
MATERIALS TRANSPORTED, kg	–	2340	2340	2340	–	2340	2340	2340	2340
CREW TIME, MAN-HR	–	1460	1460	1460	–	1460	1460	1460	1460
OPERATING POWER, kW	–	15	15	15	–	15	15	15	15
POWER DUTY CYCLE	–	0.50	0.50	0.50	–	0.50	0.50	0.50	0.50

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Fig. 3.2-54 Commercial Production Schedule for X-Ray Targets

Benefit Analysis - A comparison of costs for three different implementation approaches is shown in Fig. 3.2-55; the computations are summarized in Fig. 3.2-56. The results show that the cost of performing this mission using the Space Station is two-thirds the cost of a free flyer serviced by the STS. The cost of implementing this mission using Spacelab is an order of magnitude higher due to the large number of launches required.

The market value of an 80,000 target/year production is summarized in Fig. 3.2-51. Mission costs are for Space Station implementation; other costs include ground manufacturing and administration.

3.2.2.9 Production of Latex Spheres - The Monodisperse Latex project is an example of government/industry/university cooperation to successfully bring about a beneficial outcome. During the study, "Space Processing P/L Equipment," a number of potential projects were identified as having promise for commercial application. One of these was the project suggested by Dr. J. Vanderhof of Lehigh University. General Electric worked with Dr. Vanderhof in specifying requirements for the instrument package.

Market Analysis - The objective of the mission is to produce latex spheres in 2 to 40 microns with a very narrow 1% distribution. Such narrow distributions were unobtainable on earth due to the effect of gravity on the chemical mix during polymerization. Initial work was carried out by GE discretionary resources, while Lehigh University received NASA funds for research. Using support from NASA

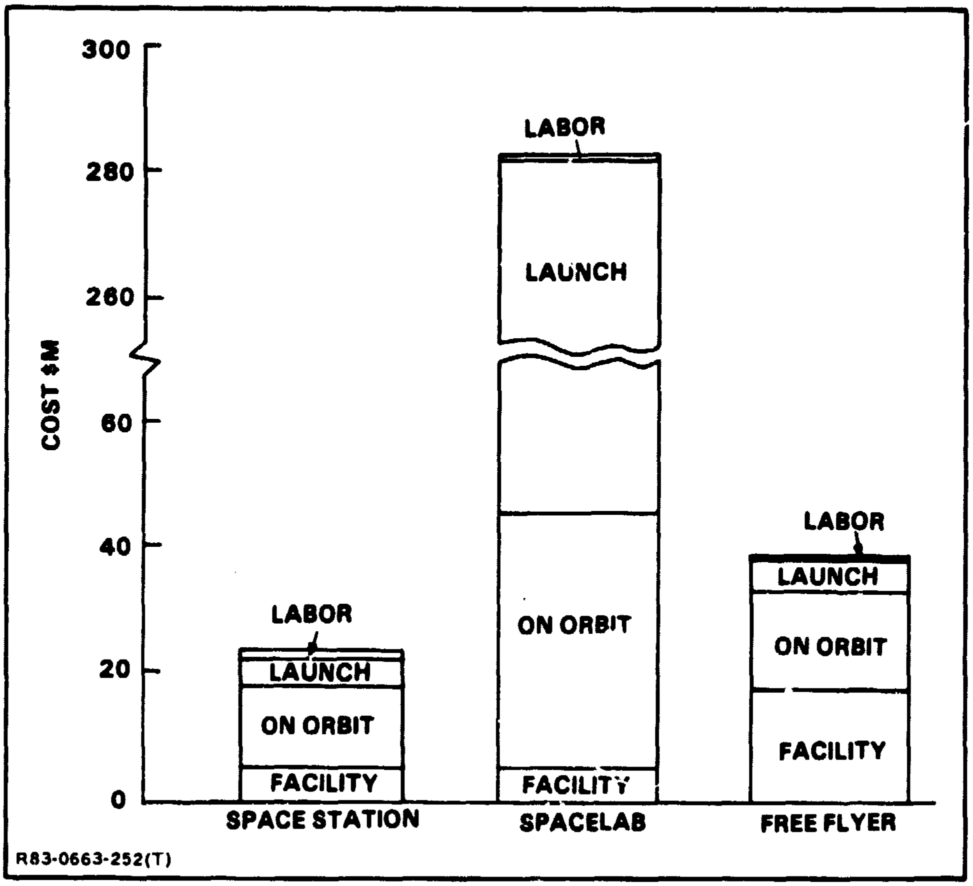

Fig. 3.2-55 Space Production of X-Ray Targets Mission Comparison

Headquarters as well as from the Marshall Space Flight Center, the project was accepted by NASA as one having the earliest possible commercial application for the use of space. The support came from the realization by Headquarters and MSFC that the polymer spheres produced would be of significant value in medical research and calibration of sensitive medical instrumentation. One immediate example is the calibration of blood sampling equipment at hospitals and diagnostic laboratories (blood platelets are on the order of 7 microns in size). Cancer research would also benefit - determination of pore size is important here. A preliminary assessment by NASA, Dr. Vanderhof and GE indicated a substantial potential market for these sizes of latex spheres. Interest was also expressed by various chemical concerns in marketing the product of these experiments (Dow Chemical and Polysciences). With this alignment, NASA has proceeded with preliminary experiments that have flown successfully on STS3 and STS4 (Columbia test flights).

COST CATEGORY		SPACE STATION		SPACELAB/STS		FREE FLYER	
LABOR:	TECHNICIAN ($10.2 M/MAN YR)	.07 MAN YEAR	0.7M	.07 MAN YEAR	0.7M	0.01 MAN YEAR	0.1M
	GROUND CREW ($1500/MAN WK)	3 HEADS	0.2M	3 HEADS	0.2M	3 HEADS	0.2M
LAUNCH:	PAYLOAD LOGISTICS SUPP. ($84.3 M/LAUNCH)	.07 P/L/5 YRS .04 P/L/YR	1.2M 3.4M	.07 P/L X 40 N/A	236 M –	.1 P/L /5 YRS .04 P/L/YR	1.7M 3.4M
	RENDEZVOUS COST ($0.88 M EACH)	.04 X 1	0	N/A	–	0.4 X 1	0
ON ORBIT:	ENERGY ($1M/KW-YR)	15 KW X 5/6 YR	12.5 M	15 KW X 4/5 YR	12 M	15 KW X 5/6 YR	12.5M
	LOITER DAYS ($0.66 M EACH)	N/A	–	N/A	–	5/YR	3.3M
	SPACELAB FLT. ($10 M EACH)	N/A	–	.07 P/L X 40	28 M	N/A	–
EQUIPMENT DDT & E/P		SEMI AUTO (PER 5 YR)	5 M	SEMI AUTO (PER 5 YR)	5 M	AUTOMATED (PER 5 YR)	7 M
SPACECRAFT DDT & E/P		N/A	–	N/A	–	DEDICATED (PER 5 YR)	10 M
TOTAL COST			23.0 M		281.9 M		38.2 M

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Fig. 3.2-56 Space Production of Tungsten X-Ray Targets (Annual Costs)

A number of criteria can be used in determining the benefit of a project such as the Monodisperse Latex to mankind. These fall in the area of economic, social and increase in performance. The General Electric Company has performed some very preliminary benefit analysis relative to the Monodisperse Latex. From the social aspect, it is clear that a product of this kind has significant social impact, should it serve to aid in the cure of a disease such as cancer. As research aids or medicine carriers which can pinpoint very specifically the application of the necessary antibiotic, the impact of the spheres is readily discernible. Economically the near term presents a challenge since initial demand and usage are marginal when compared to currently available but inferior products used in like circumstances. Figure 3.2-57 shows the results of a pricing analysis for various discounted cash rates of return used by industry. Clearly the cost will drop and hence the price, as large quantities are produced. However, the demand has to be there to ensure the validity of the result. The initial quantities will operate (near term) in the Case 1 and Case 2 areas. Future demand will permit lowering the price at the same time that a Space Station permits large batch production.

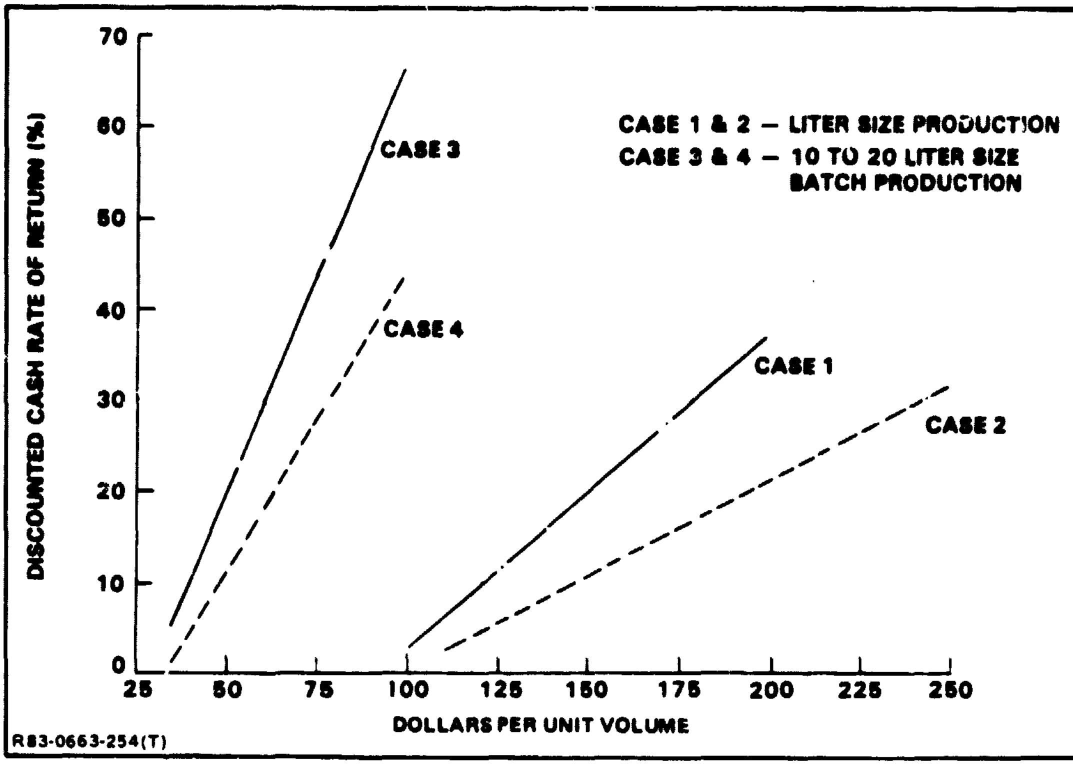

Fig. 3.2-57 Results of Economic Analyses for Latex Spheres

Mission Description - The Monodisperse Latex Spheres are produced by introducing a seed which is sequentially grown to larger sizes in a batch process. This approach is satisfactory for initial experimentation. A polymer reaction takes approximately 24 hours to complete, hence a sequential growth from 2 to 7 microns would require four days of processing. The basic production process is illustrated in Fig. 3.2-58. Figure 3.2-59 shows a near-term concept for producing batch quantities of up to 1 liter. The initial demand could be satisfied by proliferation of Space Shuttle flights carrying this equipment into orbit. Near-term demand would probably require one or two such Shuttle flights per year. However, applications of this substance could be expected to proliferate as its uses are evaluated by the chemical community.

Far-term projections can be expected to approach current demand for smaller (below 2 microns) sized latex particles. This demand requires the production in 20-liter batches and would necessitate a permanent Space Station facility that would use the Space Shuttle as a carrier of the product back to earth and to refurbish the consumables used in the polymerization reaction (see Fig. 3.2-60). The consumables would be transferred into the factory while the product, in a semi-dried

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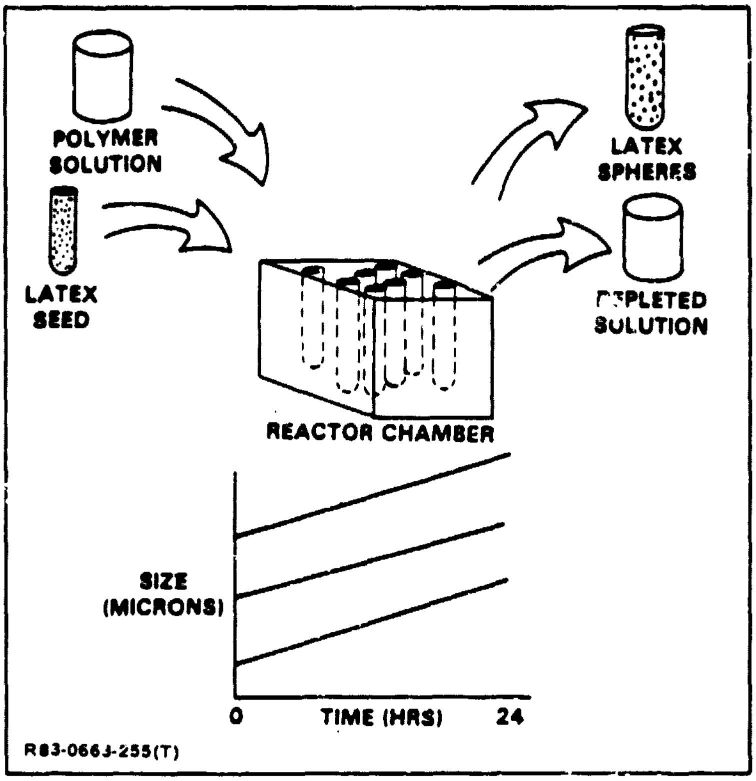

Fig. 3.2-58 Monodisperse Latex Spheres Production Process

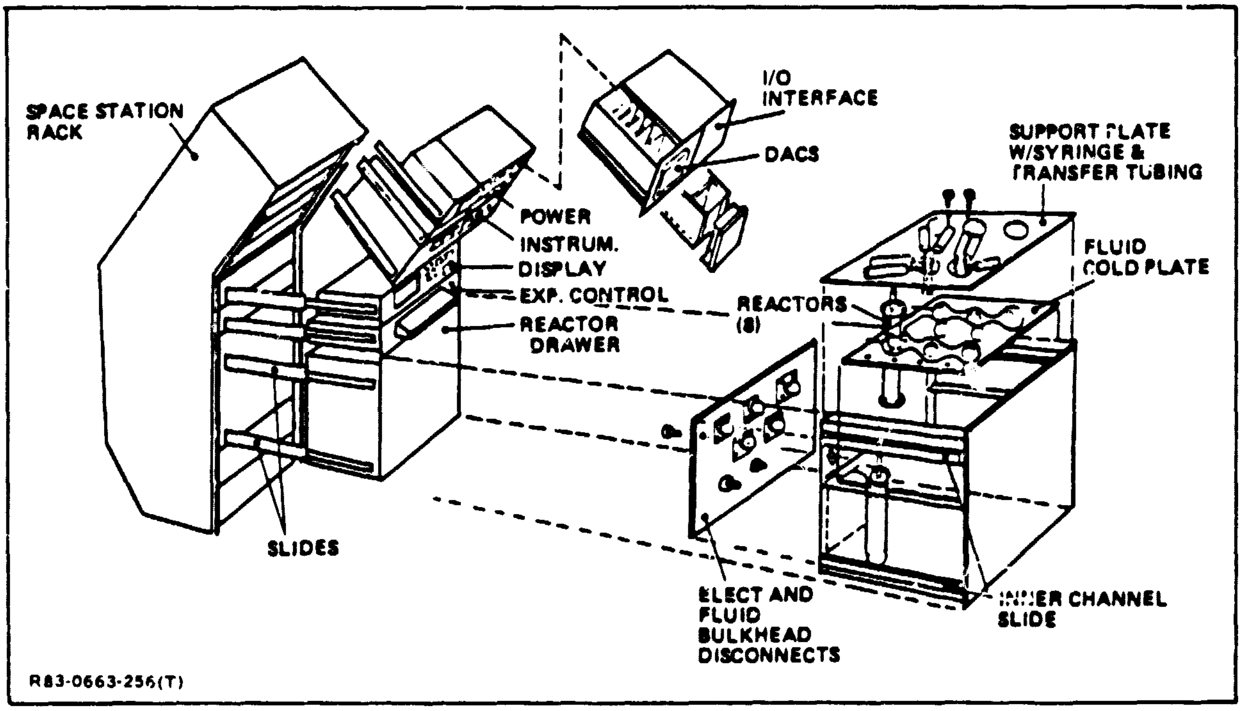

Fig. 3.2-59 PLR System Intermediate Factory (Near Term)

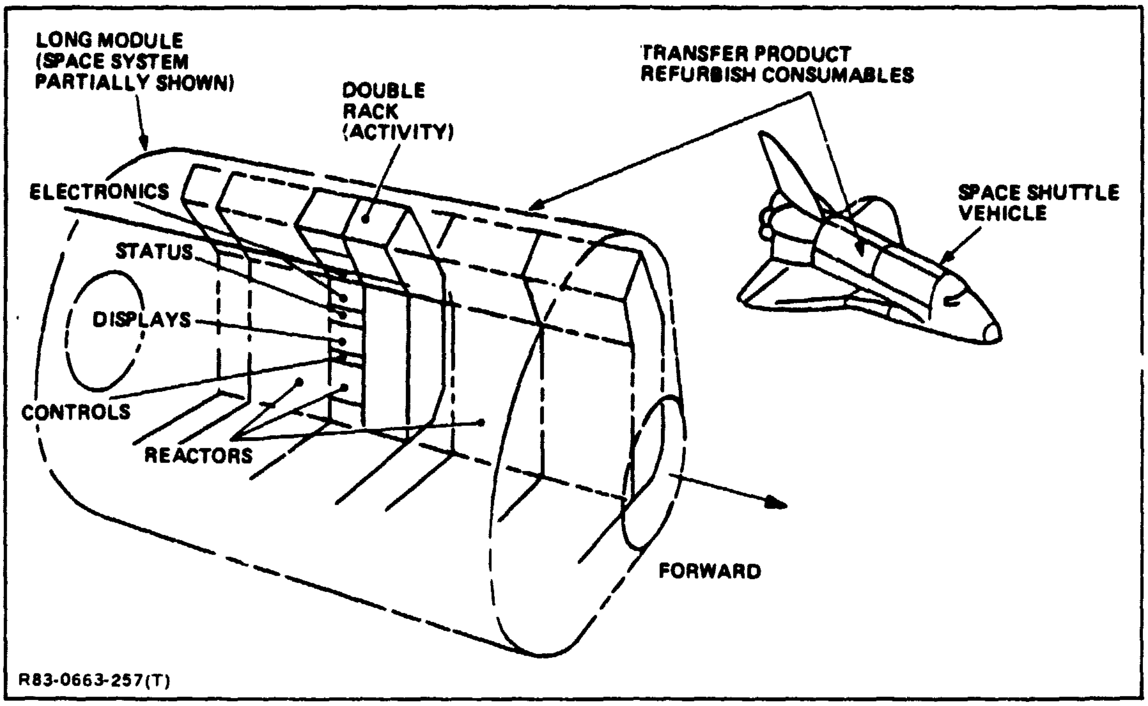

Fig. 3.2-60 Space Station Module Preliminary Concept

and therefore compact condition, would be retrieved by the Shuttle for distribution to users on earth.

Requirements - A number of 20-liter containers would be required to effectively perform the polymerization in a Space Station factory. Crew requirements are minimal since the process would be automated. A single crew member serving in a monitoring role would be sufficient. Power requirements are scaleable. The larger quantities proposed here would require less power since the reaction is exothermic. However, since cooling may then be required, the overall power requirement for the process would be 20 kW for 20 to 30 min, followed by a maintenance level of 2 kW for a reaction lasting up to 20 hr. Since up to eight reactions may be necessary to perform the batch production process, the power requirements would hold for an eight-hour duration. Crew time on the other hand is required only during loading of chemicals and transfer of reactants between containers, a process that should take at most 2 hr/operation. Therefore the crew time needed in actual active operation is 16 hr, spread over an eight-day period. The Shuttle is used for supplying the chemical reagents to the Station and for carrying the product back to earth. The significant time-phased requirements are given in Fig. 3.2-61 for the estimated annual productions. Other requirements are given in the Payload Element Data Sheets (Part IV).

	'91	'92	'93	'94	'95	'96	'97
APPARATUS TRANSPORTED	–	1	0	0	0	0	–
APPARATUS MASS TRANSP, kg	–	3000	0	0	0	0	–
APPARATUS OPERATING	–	1	1	1	1	1	–
MATERIALS TRANSPORTED kg	–	360	360	360	360	360	–
CREW TIME*, MAN-HR	–	730	730	730	730	730	–
OPERATING POWER, kW	–	2	2	2	2	2	
POWER DUTY CYCLE	–	1.00	1.00	1.00	1.00	1.00	–

*2 HR PER DAY PER APPARATUS

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Fig. 3.2-61 Commercial Production Schedule for Latex Spheres

Benefit Analysis - The three alternative implementation modes are: Space Station; Spacelab; or free flyer. The comparative cost of performing the mission in these modes is shown in Fig. 3.2-62; the computations are summarized in Fig. 3.2.63. There are some savings by performing the mission in the Space Station. However, these savings become appreciable only if the production rate is several times larger than the 20-liter capacity sized for pilot-plant demonstration on board the Shuttle.

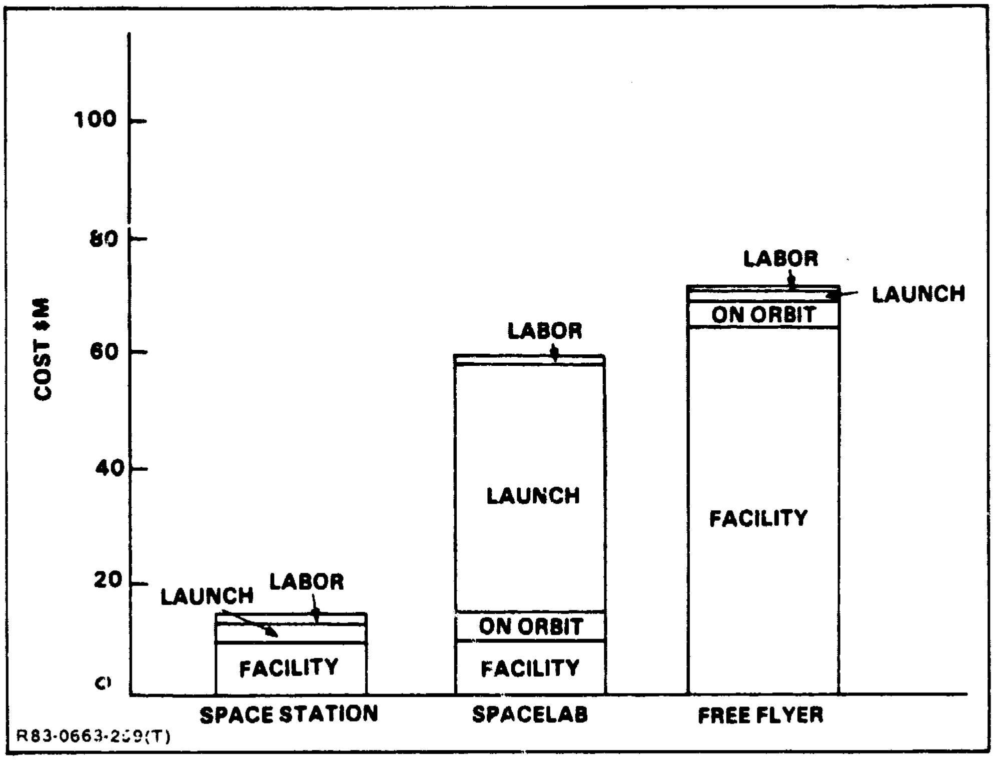

Fig. 3.2-62 Production of Latex Spheres Mission Comparison

COST CATEGORY		SPACE STATION		SPACELAB/STS		FREE FLYER	
LABOR:	TECHNICIAN ($10.2 M/MAN YR)	0.2 MAN YEAR	2.0M	0.2 MAN YEAR	2.0 M	0.01 MAN YEAR	0.1M
	GROUND CREW ($1500/MAN WK)	3 HEADS	0.2M	3 HEADS	0.2 M	3 HEADS	0.2M
LAUNCH:	PAYLOAD LOGISTICS SUPP. ($84.3 M/LAUNCH)	.07 P/L/5 YRS .01 P/L	1.2M 0.8M	.01 X 50 N/A	42.2 M –	.07 P/L/5 YRS .01 P/L	1.2M 0.8M
	RENDEZVOUS COST ($0.88 M EACH)	.01 X 1	0	N/A	–	.01 X 1	0
ON ORBIT:	LOITER DAYS ($0.66 M EACH)	N/A	–	N/A	–	5	3.3M
	SPACELAB FLT. ($10 M EACH)	N/A	–	.01 X 50	5.0 M	N/A	–
EQUIPMENT DDT & E/P		SEMI AUTO	10.0 M	SEMI AUTO	10.0 M	AUTOMATED	15.0M
SPACECRAFT DDT & E/P		N/A	–	N/A	–	DEDICATED	50.0 M
TOTAL COST			14.2 M		59.4 M		70.6 M

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Fig. 3.2-63 Production of Latex Spheres (Annual Costs)

3.2.3 Commercial Earth Observations

The mission that represents this category is the Stereoscopic Imaging System, an adaption of Stereosat, which has a clear user constituency and has been recommended by the Geostat Committee. This is not to imply that this is the only mission category which has commercialization potential; as a matter of fact, many of the Earth Observation missions included under Science and Application (see Subsection 3.3) are potentially able to be "commercial."

There are at least three ways to define "commercial mission" relative to any particular flight instrument package on the Space Station. The first and most obvious is the scenario in which a commercial entity builds the flight package and pays the government to fly it on the station and charges for the data; the Stereosat belongs in this category. While there is no current commitment to a Stereosat flight schedule and while the study involved a free flyer mission and not the station, it certainly is in a class by itself in terms of a commercial venture.

The second scenario is that in which a government agency other than NOAA or NASA builds the state-of-the-art flight package and then pays to have it flown on the station. In the current literature one can find a candidate for this scenario, namely MAPSAT, which at this point can only be ranked as a preliminary plan.

The third scenario is a variation on the first or second in which a commercial or a government agency contracts the R&D phase and the flight equipment for the mission. This scenario has the distinct disadvantage that the broad-based user community does not participate in the R&D and thus it cannot fully benefit by the technology advancements. However, there are instances where the need for proprietary right protection may dictate such a scenario.

3.2.3.1 Stereoscopic Imaging System - In the spring of 1976, The Ad Hoc Committee on Remote Sensing from Space (the predecessor to The Geostat Committee, Inc.) held a workshop to answer the question, "What do the geology-related industries want specifically from satellite remote sensing?" The 45 geologists who attended the workshop and contributed to the report entitled, "Geological Remote Sensing from Space," recommended, as a first of 10 priorities, the establishment of:

> "Worldwide stereoscopic coverage missions (Stereosat) with a base to height ratio of 0.4 to 1.0 to maximize the vertical exaggeration for geological and structural interpretation and mapping."

As a result of this recommendation, and significant baseline design work by NASA's Jet Propulsion Laboratory (JPL), this recommendation was translated into systems specifications for a stereo satellite imaging system (designated Stereosat) and funds for designing, constructing and operating the Stereosat system were requested from NASA.

To date, Stereosat has not been approved as a new start by NASA. This is in part due to the continuing debate on commercialization of earth observations and in part due to reservations as to the cost effectiveness of dedicating a satellite to the stereo imaging mission. Implementation as a "strap on" payload on Space Station offers an attractive approach to commercially viable operations.

Market Analysis - Stereoscopic data of the earth's surface is of value for both commercial and scientific geology. In general, commercial geologists are interested in specific target areas and would use worldwide survey data only to identify areas of potential interest. It is not anticipated that they would be willing to pay more than a nominal amount for worldwide survey data in which they would not have proprietary rights. The promising area for commercialization is in high-resolution on-

demand coverage of specific target areas in which full proprietary rights to the data would be retained by the customer.

This type of activity is presently performed by in situ field measurements or by aerial surveys. Orbital observations have some advantage over aerial surveys in that all areas overflown can be covered with minimum logistics problems and "red tape."

The stereo imaging system envisioned for Space Station would be flown in two phases: global mapping with fixed observational parameters; and target mapping with reconfigurable observational parameters. The first phase is of limited commercial potential, but is a useful precursor to full commercial exploitation. The second phase is envisioned as a mature profit-making venture.

The Geostat Committee (Reference 13.) estimated the U.S. and global markets for three years of Stereosat images at 32,000 and 132,000 data products, respectively. They estimated a sale price of $450 per product in 1978 dollars. Using their coverage rate of 44,000 data products/year and escalating the price to $700/data product in 1984 dollars, the annual market potential is as follows:

- Fixed observational parameters (six-month mission): 22,000 data products at $15.4M sales
- Reconfigurable observational parameters (continuing missions): 44,000 data products/year at $30,8M annual sales.

These market values are summarized in Fig. 3.2-64.

Mission Description - The objective of the initial mission is to provide global stereo mapping (resolution of 15 m) for topographic surveys. The stereoscopic imaging system would consist of a stereo film camera (Fig. 3.2-65) that could be mounted on the Space Station. It would use the results/recommendations derived from earlier shuttle developmental testing. The stereoscopic imaging system would initially map with fixed observational parameters. Later developments of the stereoscopic imaging system would also have the capability to reconfigure spectral bands, bandwidths, fields of view and pointing angles per mission requirements. The initial mission duration would nominally be six months, with extensions for missed coverage as required. Reconfiguration of the instrument with other spectral channels and fields of view would extend its mission indefinitely.

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	FIXED PARAMETERS	RECONFIGURABLE PARAMETERS
SALES	$ 15 M	$ 30 M/YR
MISSION COSTS*	$ 7.5 M	$ 7.5 M/YR
OTHER COSTS (SALES ADMINISTRATION, ETC.)	$ 3.25 M	$ 7.5 M/YR
POTENTIAL PROFIT	$ 4.25 M	$ 15 M/YR

*NOT INCLUDING SPACE STATION USAGE

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Fig. 3.2-64 Stereo Imaging System Market Value

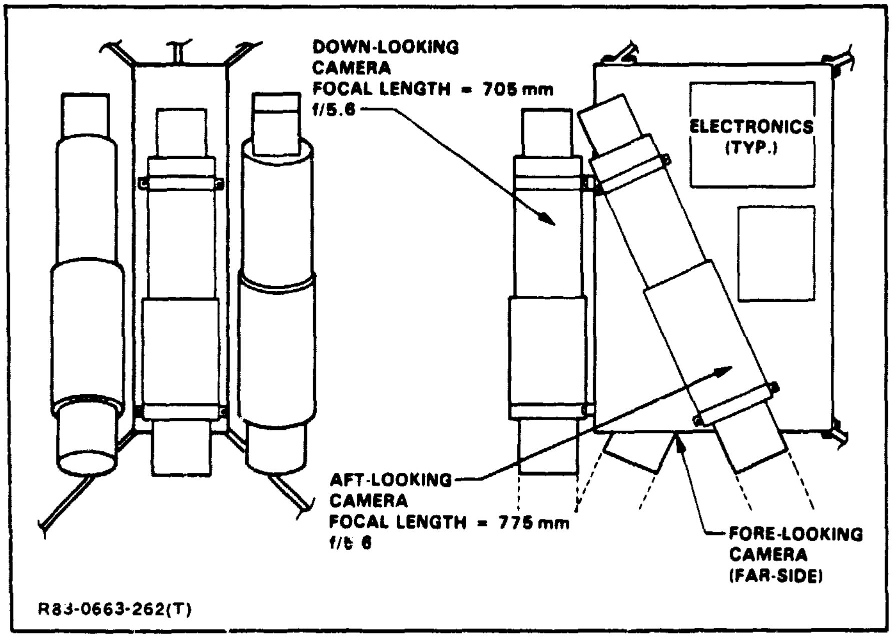

Fig. 3.2-65 Stereoscopic Imaging System

Requirements - The instrument package is a film camera (0.864 x 1.09 x 0.71 m) that requires continuous, unobstructed earth viewing, plus isolation from jitter (pointing accuracy - 0.1 to 0.01 deg). Power requirements (50 to 75 watts continuous) and command/telemetry requirements are minimal (with the possible exception of 100-Mb/sec data rates if digital imaging is used). The stereoscopic imaging system would prefer either a sun-synchronous or polar orbit, although 60 to 65 deg inclination would be acceptable. The instrument package would be externally mounted (unpressurized), and periodically calibrated and serviced by the non-dedicated crewman, using EVA. The significant time phased requirements are given in Fig. 3.2-66 for the estimated annual productions. Other requirements are given in the Payload Element Data Sheets, Part IV of this book.

	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
CAMERAS TRANSPORTED	–	3	3	–	3	3	–	3	1*	1*	1*
CAMERA MASS TRANSPORTED, kg	–	90	90	–	90	90	–	90	30	30	30
CAMERAS OPERATING	–	3	3	–	3	3	–	3	3	3	3
FILM TRANSPORTED, kg	–	190	190	–	190	190	–	380	380	380	380
CREW TIME, Man-Hr	–	168	168	–	168	168	–	336	336	336	336
OPERATING POWER, kW	–	0.08	0.08	–	0.08	0.08	–	0.08	0.08	0.08	0.08
POWER DUTY CYCLE	–	0.25	0.25	–	0.25	0.25	–	0.25	0.25	0.25	0.25

*REPLACEMENT OF EQUIPMENT

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Fig. 3.2-66 Commercial Production Schedule for Stereoscopic Imaging

Benefit Analysis - Alternative mission implementation using an unmanned free flyer would require a sophisticated electronic sensor. Deployment via the STS, operational commanding from a ground POCC via TDRSS and on-orbit servicing/recovery via the STS would be required. Mission implementation using Spacelab/STS would involve many Spacelab flights with no anticipated on-orbit servicing requirements. A comparison of implementation costs for the initial six-month mission is given in Fig. 3.2-67; the computations are summarized in Fig. 3.2-68.

Space Station mission implementation costs are lower than those for Spacelab/ STS and significantly lower than those for a satellite mission. Satellite mission implementation costs are high due to the costs of developing and operating the satellite and sensor. Space Station and Spacelab/STS offer the capability of flying a

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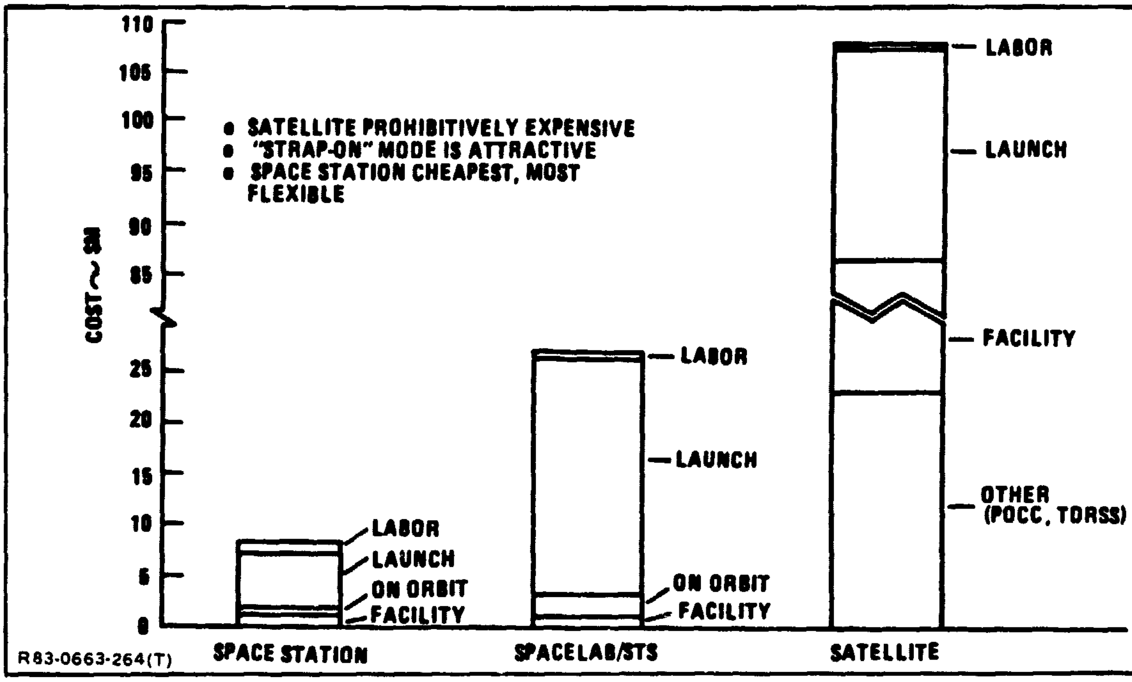

Fig. 3.2-67 Stereoscopic Imaging System Mission Comparison (Full Earth Coverage)

COST CATEGORY		SPACE STATION		SPACELAB/STS		SATELLITE	
Labor	Space Tech. ($10.2M/Man Yr)	2 Man Wk.	$0.39M	~0	-	N/A	-
	Ground Crew ($1500/Man Wk)	3 x 24 Wks	$0.1M	3 x 24 Wks	$0.1M	3 x 24 Wks	$0.1M
Launch	Payload Launch Logistics Support ($84.3M/Launch)	6.7% x 1 ~0%(Film)	$5.6M 0	6.7% x 4 N/A	$22.4M -	25% x 1 N/A	$21.1M -
	Rendezvous Cost ($0.88M Ea.)	6.7% x 1 +0% x 5	$0.06M	N/A	-	N/A	-
On Orbit	Loiter Days ($0.66M Ea.)	N/A	-	N/A	-	N/A	-
	Standard EVA ($20K Ea.)	10	$0.2M	N/A	-	N/A	-
	Spacelab Flight ($10M Ea.)	N/A	-	6.7% x 4	$2.68M	N/A	-
Facility	DDT&E & Production	Camera	$1M	Camera	$1M	Sensor + S/C	$50M
	OPS Support (15% DDT&E)		$0.15M		$0.15M		$7.5M
Other	POCC	N/A	-	N/A	-	Eqpt & Ops	$25M
	TDRSS					6 Mos	$3.25M
	TOTAL COSTS	$7.5M		$26.33M		$106.95M	

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Fig. 3.2-68 Stereoscopic Imaging System Cost Comparison

stereoscopic camera in a low-cost strap-on mode. Spacelab/STS requires numerous flights for full cloud-free earth coverage. This results in transportation costs that are much greater than those for a Space Station mission.

The market value of initial fixed parameter operation and continuing reconfigurable parameter operation is summarized in Fig. 3.2-64.

The steroscopic imaging system would benefit: geological surveys by indicating subsurface feature; the assessment of global mineral resources; the identification of hydrological topographic features; and the delineation of faults and various soil types.

In summary, implementation of the stereoscopic imaging system via the Space Station is not only cost-effective, but also allows for a relatively easy on-orbit servicing capability, as compared to either the free flyer or Spacelab/STS implementation approaches.

3.3 SCIENCE & APPLICATIONS

The personnel of Grumman and General Electric updated current science and applications mission data based on many data and personnel sources; the primary published resources used appear in Fig. 3.3-1. The last document listed, "Science and Applications Requirements for Space Station," is the most recent publication; therefore, the requirements contained therein have priority over earlier documentation. All of the science and application missions actively considered for Space Station are discussed in this section. Those missions that survived the evaluation/screening process and formed the Baseline Mission Model are summarized in Subsection 2.3. Part II contains a complete package of the mission description data prepared by General Electric personnel and Part IV of this volume, represents the input to the NASA Space Station Requirements Data Base.

Figure 3.3-2 categorizes the science and application missions by Space Station support functions. Three generic types of facilities must be provided: (1) pressurized shirt sleeve environment for internal payloads; (2) support for externally mounted payloads; and (3) service facilities for free flyers. All three generic facilities are required to support mission-related proof of concepts, experiments and equipment development for all science and application mission categories. Service

- UAH/NASA WORKSHOP ON SPACE SCIENCE PLATFORM, AUG. 21-25, 1978
- PROJECT CONCEPT SUMMARIES, NASA, OCT 1980
- SPACE SYSTEMS TECHNOLOGY MODEL, NASA, SEPT 1981
- SPACE OPERATIONS CENTER SYSTEMS ANALYSIS STUDY EXTENSION, GRUMMAN, JAN 1982
- SCIENCE & APPLICATIONS SPACE PLATFORM PAYLOAD ACCOMODATIONS STUDY, SP 82-MSFC-2583, MAR 1982
- SCIENCE & APPLICATIONS REQUIREMENT FOR SPACE STATION (DRAFT) MID-TERM BRIEFING HANDOUT, NOV 1982.

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Fig. 3.3-1 Primary Documentation Resources

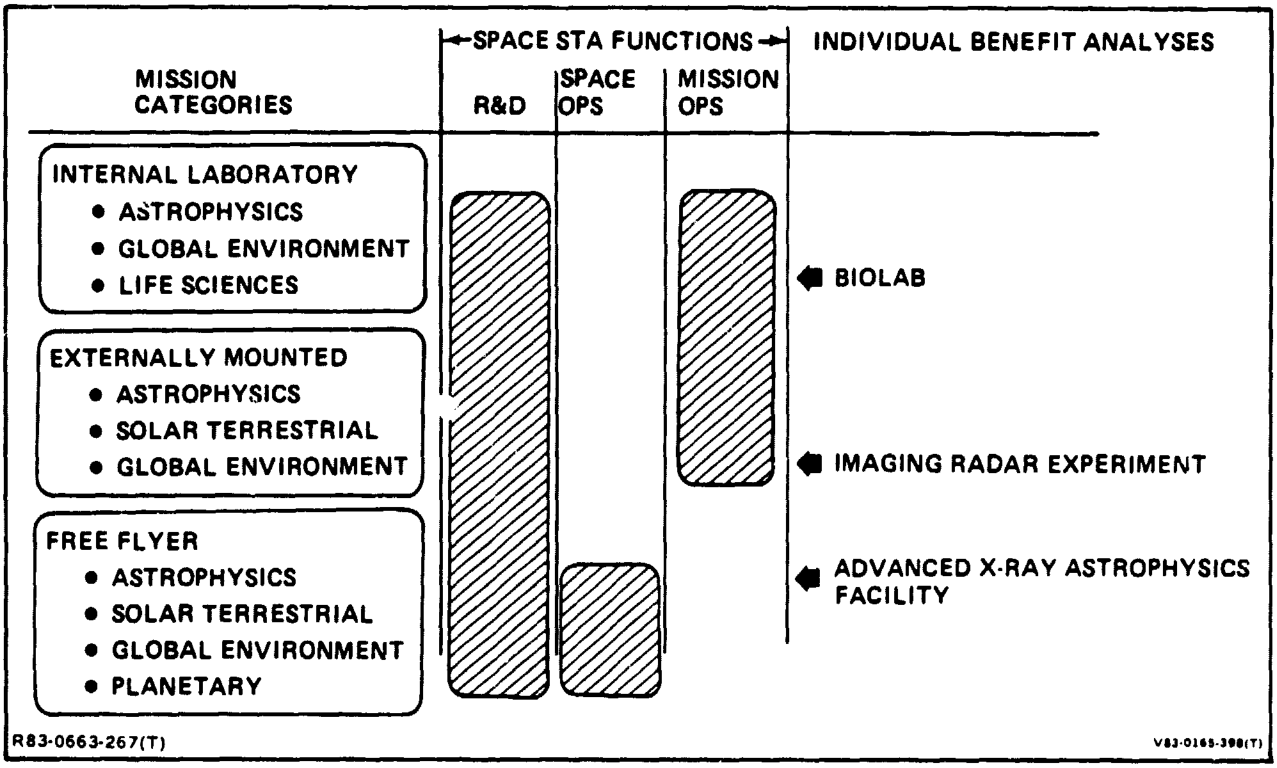

Fig. 3.3-2 Space Station Related Science & Applications Missions

operations are required for internally and externally mounted payloads, in addition to free flyers that can benefit from on-orbit service support. The free flyers not only require the traditional type of support such as replenish consumables and equipment replacement, but also assembly, deployment and retrieval. Mission equipment that is operated from the Space Station is limited to those that are resident in/on the facility.

We have done benefit analysis for the Biolab, Imaging Radar Experiment and the Advance X-ray Astrophysics Facility. These analyses show the cost advantage of space operations when the Space Station is available, and are reported in subsequent subsections and Appendix A.

3.3.1 Astrophysics

Astrophysics missions implementation requires a pressurized laboratory in space (internal), platform (external) mounting provisions, and free flyer dedicated space vehicles. Figure 3.3-3 lists the missions that have applicability to the Space Station either for continuous support or such intermittent operations as servicing, and

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	INTERNAL PAYLOAD				
0100	GEOLOGICAL PROCESS IN LOW GRAVITY	98	ANY	ANY	N/A
	EXTERNAL PAYLOADS				
0201	SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF)	88	28.5-57	400	CELESTIAL
0202	STARLAB	87	28.5	400	CELESTIAL
0203	VERY LONG BASELINE INTERFEROMETER PAYLOAD (VLBIP)	91	>45	400-5000	CELESTIAL
0204	LARGE AREA MODULAR ARRAY (LAMAR)	95	28.5	400	CELESTIAL
0205	HIGH RESOLUTION X-RAY & GAMMA RAY SPECTROMETER (HRS)	94	<45	ANY	CELESTIAL
0206	GAMMA RAY TRANSIENT EXPLORER (GTE)	99	28.5	450	CELESTIAL
0207	COSMIC RAY OBSERVATORY (CRO)	93	56	400	CELESTIAL
0208	X-RAY OBSERVATORY (XRO)	98	28.5	400	CELESTIAL
0209	MULTICHANNEL ASTROMETRIC PHOTOMETER (MAP)	2000	28.5	550	CELESTIAL
0210	HEAVY NUCLEI EXPLORER (HNE)	95	56	400	CELESTIAL

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Fig. 3.3-3 Space Station Astrophysics Missions (Sheet 1 of 2)

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	FREE FLYERS MISSIONS				
0301	SPACE TELESCOPE (ST)	86	28.5	600	CELESTIAL
0302	GAMMA RAY OBSERVATORY (GRO)	88	28.5	400	CELESTIAL
0303	EXTREME ULTRAVIOLET EXPLORER (EUVE)	87	28.5	550	CELESTIAL
0304	X-RAY TIMING EXPLORER (XTE)	88	28.5	400	CELESTIAL
0305	GRAVITY PROBE B	88	90	550	CELESTIAL
0306	ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)	90	28.5	500	CELESTIAL
0307	EXTREME UV SPECTROSCOPY EXPLORER (EUVSE)	97	28.5	500	CELESTIAL
0308	X-RAY SPECTROSCOPY (XSE)	2000	28.5	450	CELESTIAL
0309	SOFT X-RAY EXPLORER (SXE)	2000	28.5	400	CELESTIAL
0310	MOLECULAR LINE SURVEY (MLSE)	2000	28.5	600	CELESTIAL
0311	LONG DURATION EXPOSURE FACILITY (LDEF)	83	28.5-57	ANY	ANY
0312	ORBITING VERY LONG BASELINE INTERFEROMETER (OVLBI)	98	>45	400-5000	CELESTIAL

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Fig. 3.3-3 Space Station Astrophysics Missions (Sheet 2 of 2)

sketches of some of these are in Fig. 3.3-4. Figure 3.3-5 lists the astrophysics mission documentation resources. Most of the missions can be operated at low inclination and low orbital altitude, and require pointing compatible with viewing the celestrial sphere. Descriptive information about potential internal and externally mounted Space Station payloads follow in subsequent subsections. The free flyer missions interfacing with the Space Station are mating an upper stage for transportation of the spacecraft to its operational orbit and/or to service them at the required interval.

3.3.1.1 Geological Process in Low Gravity (GRUM 0100) - To more deeply understand the processes that controlled formation and evolution of the planets, laboratory experiments are conducted to constrain the theoretical models. Some physical processes that operate on the planets (including the earth) can be studied and more completely characterized by conducting experiments in earth orbit where advantage can be taken of the unique gravity, pressure and radiation environments provided by a Space Station. An on-orbit laboratory could provide experimental conditions where select parameters can be varied. For example, material transport and erosion, and impact cratering experiments would be greatly enhanced by varying gravity; condensation and agglomeration experiments require zero gravity and variable pressure; and material exposure experiments require the raw space environment.

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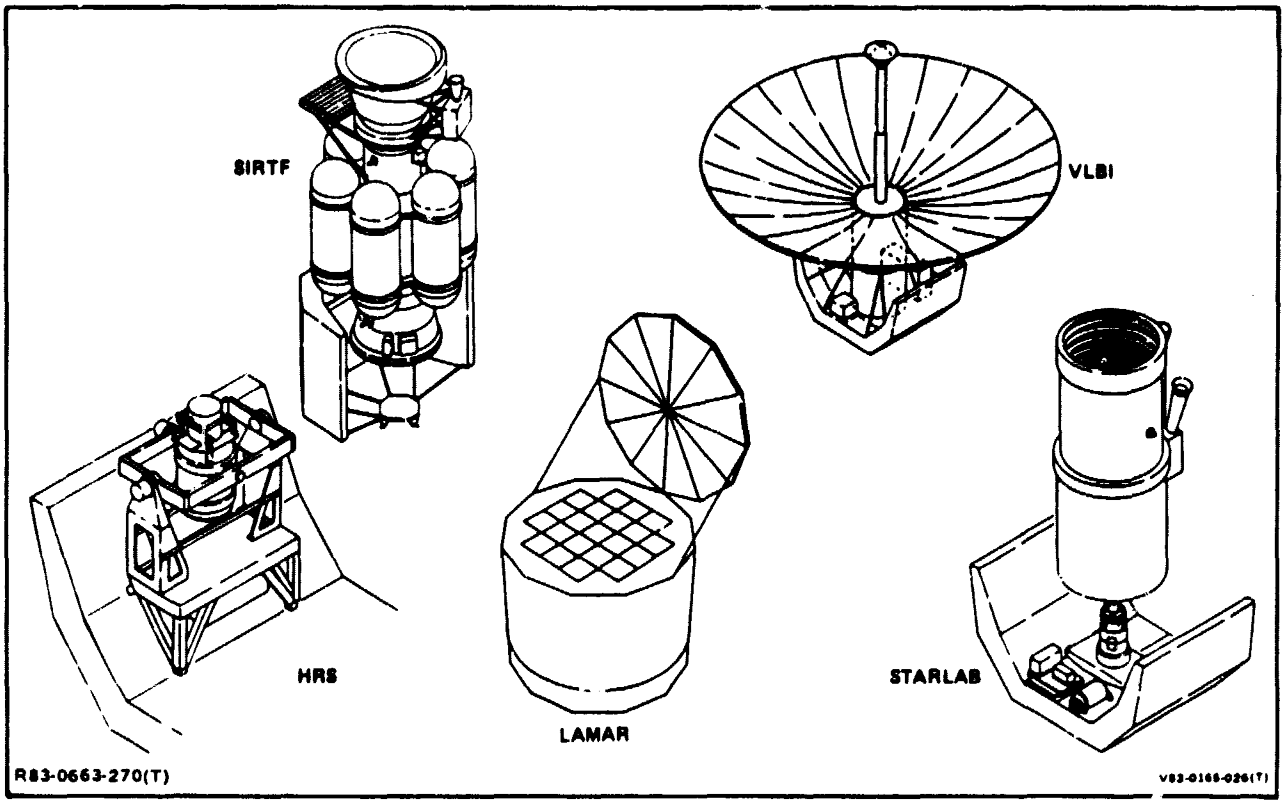

Fig. 3.3-4 Astrophysics External Payloads

ID NO.	MISSIONS	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES: UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–	INTERNAL PAYLOAD						
0100	GEOLOGICAL PROCESS IN LOW GRAVITY	PAGE 68					PAGE 79
	EXTERNAL PAYLOAD						
0201	SHUTTLE INFRARED TELESCOPE FACILITY	PAGE 46	•	S-15		PAGE A-1	PAGE 11
0202	STARLAB	PAGE 43	•	S-13		PAGE A-13	PAGE 10
0203	VERY LONG BASELINE INTERFEROMETER	PAGE 48	•	S-29	•	PAGE A-25	PAGE 12
0204	LARGE AREA MODULAR ARRAY	PAGE 21	•	S-14	•	PAGE A-51	PAGE 14
0205	HIGH RESOLUTION X-RAY & GAMMA-RAY SPECTROMETER					PAGE A-50	PAGE 16
0206	GAMMA-RAY TRANSIENT EXPLORER		•	S-41			
0207	COSMIC RAY OBSERVATORY	PAGE 17		S-23	•	PAGE A-37	PAGE 16

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Fig. 3.3-5 Astrophysics Missions Documentation (Sheet 1 of 3)

ID NO.	MISSIONS	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES: UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–							
0208	X-RAY OBSERVATORY	PAGE 14	•	S-27	•		
0209	MULTICHANNEL ASTROMETRIC PHOTOMETER						PAGE 83
0210	HEAVY NUCLEI EXPLORER	P-11	•	S-38			
	<u>FREE FLYER MISSIONS</u>						
0301	SPACE TELESCOPE			S-3	•		
0302	GAMMA RAY OBSERVATORY			S-9	•		PAGE 15
0303	EXTREME UV EXPLORER		•	S-10	•		
0304	X-RAY TIMING EXPLORER		•	S-11	•		
0305	GRAVITY PROBE B		•	S-14	•		
0306	ADVANCED X-RAY ASTROPHYSICS FACILITY	PAGE 25	•	S-17	•		

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Fig. 3.3-5 Astrophysics Missions Documentation (Sheet 2 of 3)

ID NO.	MISSIONS	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES: UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–							
0307	EXTREME UV SPECTROSCOPY EXPLORER		•	S-44	•		
0308	X-RAY SPECTROSCOPY		•	S-39			
0309	SOFT X-RAY EXPLORER		•	S-40	•		
0310	MOLECULAR LINE SURVEY		•	S-45	•		
0311	LONG DURATION EXPOSURE FACILITY			OI-17			
0312	ORBITING VERY LONG BASELINE INTERFEROMETER		•	S-29			

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Fig. 3.3-5 Astrophysics Missions Documentation (Sheet 3 of 3)

3.3.1.2 Shuttle Infrared Telescope Facility (SIRTF) (GRUM 0201) - Observational infrared astronomy is severely limited over most of its wavelength range by atmospheric absorption and intense background emission from warm optics and the atmosphere. An infrared observatory placed above the absorbing and emitting terrestrial atmosphere with optics cooled sufficiently to reduce their radiation below the natural background would be an enormously powerful tool for astronomy.

The SIRTF will be a cryogenically cooled, approximately 1.5-m dia telescope designed for flights on Spacelab. This instrument's spectral coverage will extend to 1 mm. Such a telescope, with optics cooled below 20°K, would observe against background radiation at least 10^6 times lower than ground-based telescopes. Over much of three decades of the infrared wavelength range, the SIRTF will provide a 1000-fold increase in sensitivity over presently available facilities.

The SIRTF will commence operations on a Spacelab pallet in 1988 and when Space Station/platform is available, the SIRTF could be mounted on it to obtain extended orbital operation time.

3.3.1.3 Starlab (GRUM 0202) - An attractive feature of flying on Spacelab is the relative ease in preparing the instrument for space observations. Much of the overhead of the support systems can be taken over by standardized equipment associated with the Spacelab, and the payload operations can be run or supervised by personnel in space. Furthermore, the equipment can be modified between successive flights, thus permitting more operational flexibility and making specialized configurations more justifiable.

There is, however, a serious drawback of operating instruments aboard Spacelab. A vast majority of the proposed astronomical observing programs require a great deal of time, and when one draws comparisons with free flyers, the large disparity of time available becomes apparent. In this context, for instance, we may consider the coverage by the wide field camera on Starlab, and compare it with its counterpart aboard the Space Telescope (ST).

A principal aim of the Starlab camera is to provide a relatively large field of view (0.5-deg dia) with an angular resolving power and limiting magnitudes that surpass those obtainable from the ground. For individual small objects, the Starlab camera performance is inferior to that of the ST, but its 90 times larger field area

serves well those programs which require more coverage of the sky, such as searches for new objects or imaging of sources with large angular scales. The differences between ST and Starlab are analogous to those of earth resources satellite and conventional aerial photography; in both situations the contrast in resolution and coverage makes each mode serve different observing objectives.

In the regime in which photon statistical uncertainties dominate other sources of noise (e.g., detector dark current or readout noise, diffuse sky background light, cosmic rays, etc), we find that, to a first approximation, the Starlab camera can survey point sources to a given limiting magnitude over 16 times as much solid angle per unit of exposure time as can the ST. However, this strong survey advantage of Starlab is badly eroded by the low observing time duty factor which would be realized from successive Shuttle sorties. If Starlab could fly twice a year and each flight could last two weeks, one has to first order an observing duty factor of 1/13 per year. This reduces the coverage advantage of Starlab to only 2.5 times that of ST, which may not be a large enough gain to justify the building and use of this instrument. If one removes the restriction of operating Starlab only during Shuttle flights, on the other hand, the low duty factor is no longer a problem and Starlab has a clearly recognizable importance for field coverage.

3.3.1.4 Very-Long-Baseline Interferometer Mission (GRUM 0203) - Very-long-baseline interferometry (VLBI) extends the angular resolution of radio telescopes to sub-milli arc-seconds and appears, potentially, to be able to yield angular resolutions in the micro arc-second range or better. By adding a space-based VLBI station to the existing ground-based network, one essentially can synthesize a high-quality radio telescope as large as earth.

The VLBI missions (GRUM 0203 and GRUM 0312) have requirements that can be implemented incrementally; that is, one space-based set of instruments can complement ground-based installations, and later, a second space-located set of instruments, at different orbital parameters, can further enhance the received data. The first set of instruments to be placed in orbit could be externally mounted on a Space Station or other tended platform.

3.3.1.5 Large Area Modular Array (GRUM 0204) - The large area modular array of reflectors (LAMAR) will be developed as a Spacelab facility in X-ray astronomy.

Its objectives encompass a wide variety of studies in high energy astrophysics with particular emphasis on: the deep all-sky survey; the detection and imaging of diffuse matter; time variations in faint sources; and non-dispensive spectroscopy combined with imaging. The major features of the LAMAR are large collecting area, good angular resolution to avoid source confusion, and a modular concept. The effect of modularity is to reduce technical complexity, facilitate testing and integration, and allow an evolutionary development with substantial growth potential. It is clear that a single seven-day Shuttle mission or a series of short duration missions will provide sufficient time for only a small fraction of the possible studies that researchers will wish to carry out with the LAMAR. A very large LAMAR mounted on a Space Platform/Station can be built up over a period of many years by adding additional modules of 10^4 cm^2 aperture through a series of Shuttle launches. Since this is a modular instrument, observations can be carried out through this entire period.

3.3.1.6 High Resolution X-Ray and γ-Ray Spectrometer (GRUM 0205) - In the future, a gamma ray telescope system with high spectral resolution will be developed to investigate the information about nucleosynthesis in the galaxy contained in narrow gamma ray lines of naturally radioactive elements. The energy range between 100 keV and 10 MeV contains these lines. A high resolution X-ray and Gamma ray spectrometer (HRS) could be operated from an unmanned Space Platform. Like the other future missions in astrophysics that have been studied, it can be accommodated on a free flyer and serviced by a Space Station. It might also be accommodated in an attached mode to the Space Station.

3.3.1.7 Gamma Ray Transient Explorer (GRUM 0206) - The Gamma Ray Transient Explorer will be used to study the cosmic Gamma-ray transient, with all-sky coverage and solar flare Gamma-ray transients with very accurate spectral measurements.

Data from the high resolution Gamma ray and scintillation spectrometers, the Dicketype cameras and the X-ray sky monitors are used to prepare maps of the sky that show photon energy levels or pulse heights as functions of time and sensor pointing direction for each orbit traversed. The succession of maps would be used to generate high spectral resolution charts showing Gamma ray sources, spectra and time variations.

This mission is presently conceived as a free flyer; however, its planned operation trajectory (28.5 deg inclination and 450 km circular orbit) makes its instruments candidates for mounting on the Space Station.

3.3.1.8 Cosmic Ray Observatory (GRUM 0207) - The main objective of cosmic ray astrophysics is to find out how these particles got their enormous energies. This can be investigated by observing the composition which should reflect the composition at the source and by measuring the spectra which carries information on the physical processes that performed the primary acceleration. Except for a few very abundant atoms like iron, the heavier the nucleus and the more energetic the cosmic r the rarer it is.

Studies have shown how this investigation could be adapted to an unmanned Space Platform and have illustrated that its requirements are easily satisfied. It is typical of the other cosmic ray experiments that have been proposed. Some more stringent requirements have been identified for another experiment proposed for Spacelab, the Transition Radiation and Ionization Calorimeter (TRIC), which would be able to observe electrons, protons and helium nuclei energies of 10 TeV from Spacelab and 100 TeV from a year's operation in orbit. At these energies, we know from observations on the ground that there is a major change in the composition of cosmic rays, and it is a major objective of cosmic ray astrophysics to find out what the change is.

Another important area of future cosmic rays research is the isotopic composition at energies above 1 GeV. This can best be done with a long exposure from a high inclination orbit. The High Energy Isotope Experiment (HEIE) requirements would be similar to SCRN or TRIC, but the orbit must be inclined at least 57 deg. Cosmic ray investigations have the least restrictive pointing and contamination requirements of any discipline in astrophysics and should be easily accommodated in an attached mode to a Space Station.

3.3.1.9 Multichannel Astrometric Photometer (GRUM 0209)

While space telescope may have the ability to detect giant planets revolving about nearby stars, it is not capable of conducting a statistically meaningful survey of possible planetary systems. One way of conducting such a survey is the use of space-based astrometric telescope. Clestial bodies revolve about the center-of-mass of the system in which they exist. In the case of a single star, the center-of-mass

coincides with the center of the star. However, the center-of-mass (barycenter) of the planetary system does not coincide with the volumetric center of the star. In th case of our sun, the barycenter is often located outside the surface of the sun. Thus, our sun, and any star with a planetary system, will be observed to wobble as it travels through interstellar space. With sufficient observational accuracy, this wobble can be observed relative to the surrounding stars in the field of view of a telescope. The preferred method of making these observations uses an astrometric satellite. By placing this telescope on the Space Station/Platform, the long-duration observations required can be satisfied.

3.3.1.10 Heavy Nuclei Explorer (GRUM 0210) - The Heavy Nuclei Explorer would study the charged composition of nuclei from iron throughout the periodic table with a charged resolution of $\sigma = 0.3e$. This provides answers to questions regarding the origin, acceleration and propagation of Cosmic rays, which have mystified astrophysicists for the past 10 years.

This payload has been previously conceived as a free flyer; however, its orbital parameter requirements, 56 deg inclination, 400 km orbit and pointing at local zenith, make it a candidate for the Space Station/Platform.

3.3.1.11 Advanced X-Ray Astrophysics Facility (AXAF) (GRUM 0306) - The benefits of servicing the AXAF from the Space Station (when compared to operating from the Shuttle alone) are discussed in subsequent paragraphs. The schedule of activities shown in Fig. 3.3-6 is based on an initial launch in 1992 instead of earlier published dates, as a result of budgetary analysis of projected funds in future years. The AXAF is planned to be serviced after two to three years' operation; Fig. 3.3-7 illustrates replenishment of consumables, replacement of instruments and subsystem components; later it will be reboosted to higher altitude to compensate for orbital decay. It could be returned to earth for major overhaul; however, with Space Station available for servicing, this work could be performed on orbit, saving transportation costs. At present, the service life is projected to be 10 to 15 years, which could require four service revisits.

The requirements imposed on the Space Station to service the AXAF are listed in Fig. 3.3-8. This involves storage of consumables, instruments and subsystems on the Space Station until AXAF servicing. Because the AXAF has no onboard propulsion, it is necessary to provide a teleoperator maneuvering system (TMS) to

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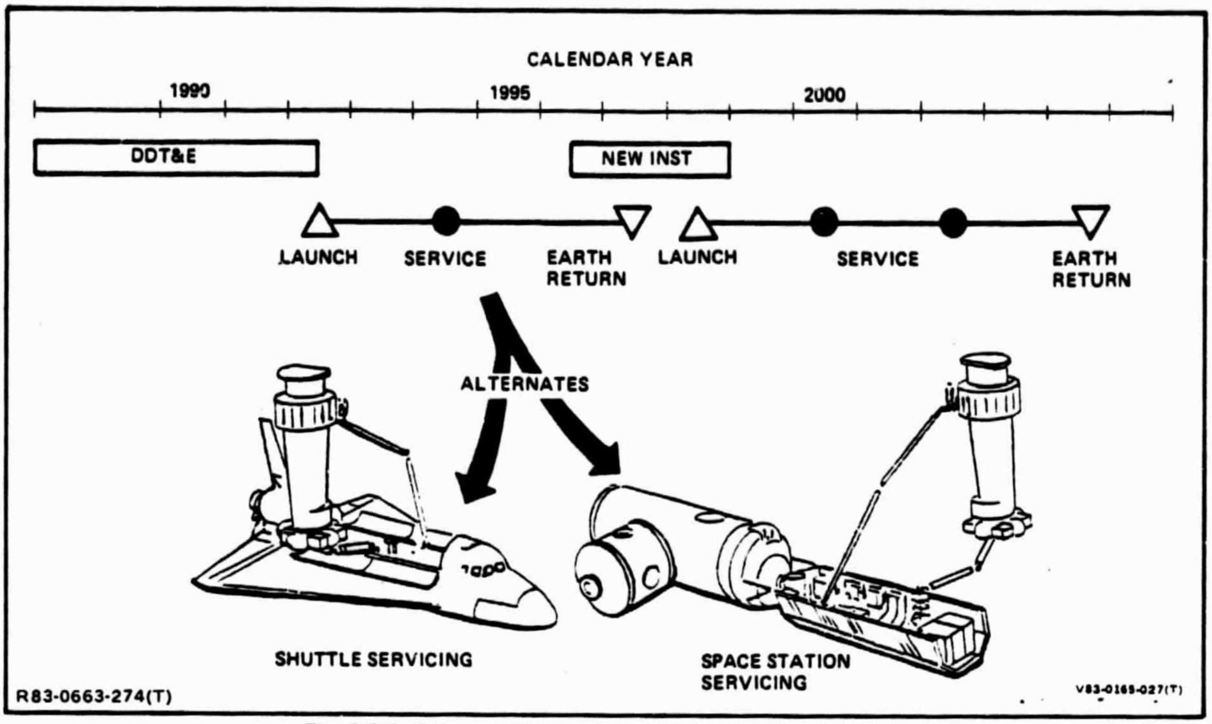

Fig. 3.3-6 Advanced X-Ray Astrophysics Facility Schedule

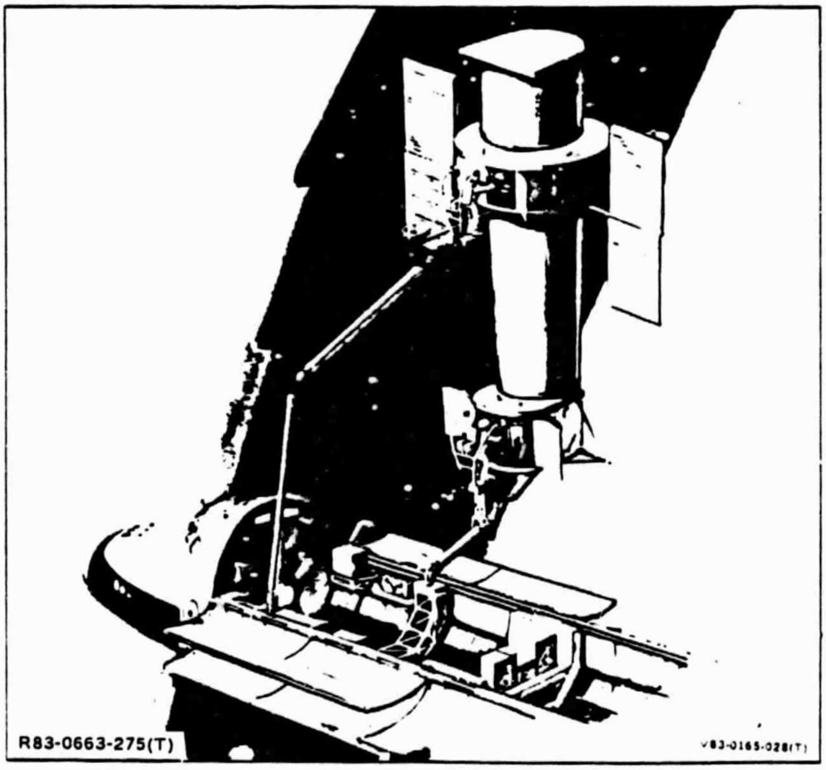

Fig. 3.3-7 AXAF Servicing by Orbiter

- RECONFIGURE/REPLACE SCIENCE INSTRUMENTS
- MAINTAIN/REPAIR: S/S ORUs, GYRO SENSOR, ANTENNAS SOLAR ARRAYS, RATE GYRO, STAR TRACKER
- RESUPPLY DETECTOR GASES & CYROGENS

} • 1 PERSON EVA 11 HR TOTAL • 1 PERSON RMS OPS • OPS 6 DAYS TOTAL INCLUDING FETCH, SERVICE & DEPLOY AXAF

- CHECKOUT: PROVIDE POWER (2,000W), CONTROLS & DISPLAYS (AXAF DATA LINK via TDRS TO PAYLOAD OPS CONTROL CENTER)
- SUPPORT EQUIPMENT
  - INSTRUMENT & S/S STORAGE
  - TMS TO FETCH & DEPLOY AXAF (10,000 kg)
  - HPA FOR HOLDING/POSITIONING (10,000 kg)
  - OCP FOR CREW SUPPORT
  - RMS FOR EQUIPMENT TRANSFER.

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Fig. 3.3-8 AXAF On-Orbit Service Requirements

fetch the AXAF and subsequently deploy it to operational orbit. It should be recognized that servicing is also required for the TMS, i.e., propellant transfer and subsystem repair as required, plus a handling and positioning aid (HPA) for holding the TMS. Means of supporting the AXAF is required during servicing; therefore, a second HPA is listed. EVA is used as the method of replacing equipment so an open cherry picker (OCP) is needed for crew transportation/support and a manipulator for transferring equipment. Checkout power and associated controls and displays will be provided with instrument data, etc relayed to the ground for evaluation.

Replacement parts and consumables are delivered to the Space Station by orbiter logistic flights. These flights would occur on a regularly scheduled basis, meeting anticipated demands for satellite servicing operations and, therefore, would not impact plans for maintenance on any particular satellite.

The TMS is checked out, then sent to fetch the AXAF under control of the TMS payload operations control center (POCC) and bring it to the Space Station for maintenance. Twenty-four hour rendezvous time has been allowed each way in Fig. 3.3-9, since phasing could take considerable time. Three EVAs were judged sufficient to replace malfunctioning equipment. After the AXAF has been buttoned up, 3.5 hours are allocated for remote checkout from the Space Station operations room in conjunction with the AXAF POCC. Then the AXAF is mated to a TMS for subsequent redeployment. Time for redeployment is approximately one-quarter of that for retrieval because phasing is not a factor. The time for nominal AXAF service operations is $6\frac{1}{2}$ days. This could easily be extended if problems developed during servicing. A contingency time of one day has been allocated.

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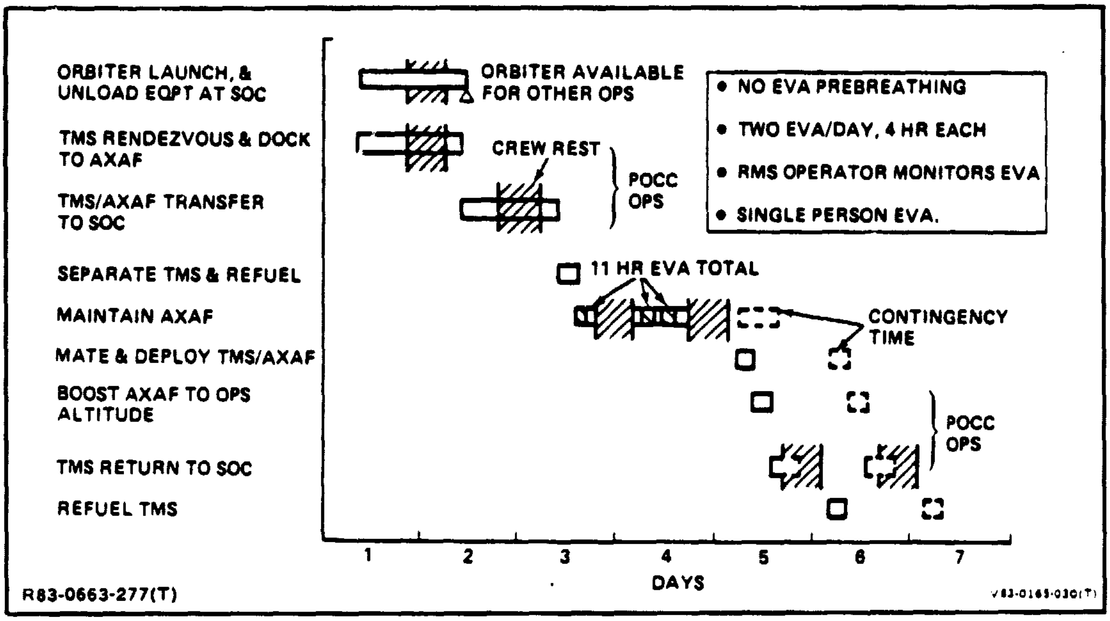

Fig. 3.3-9 Timeline — AXAF Servicing from Space Station

Comparative data of AXAF servicing from the Space Station and Orbiter is shown in Fig. 3.3-10. All parameters compared are similar, except costs for planned operations and cost allowance for contingencies. The significant cost driver is the cost associated with transportation of equipment to orbit and is discussed subsequently.

Comparison of costs to service the AXAF using the orbiter or the Space Station shows a significant advantage for Space Station operations. In Fig. 3.3-11, we have also summarized costs associated with a smaller satellite, the Large Area Modular Array X-Ray Telescope. This satellite is typical of a group that makes use of Multimission Modular Spacecraft as the basic support system for specific instruments. A similar conclusion is reached that is more economical to operate from the Space Station. Note that this payload is a candidate for attached payload GRUM 0204. The major cost driver for either approach is transportation of equipment to orbit. The orbiter transports the necessary support equipment to orbit each time it performs servicing shown in Fig. 3.3-12, in contrast to the Space Station which already has the equipment available for use. Transportation of replacement equipment and consumables is also more economical for Space Station operation, because logistic planning allows full orbiter cargo bay flights to Space Station (economy of

MISSION PARAMETER	S/S	ORBITER	COMMENTS
NO. OF ORBITER FLIGHTS	1	1	AXAF REPLACEMENT EQUIP. EQUIP. & TMS PROP. DELIVERED TO SOC BY SHARED LOGISTIC FLIGHT
MISSION TIME IN DAYS	5.5	4	AXAF/SOC OPERATIONS (ORBITER SHARED LOGISTICS FLIGHT NOT INCLUDED)
NO. CREW (AXAF WORKERS)	2	2	SINGLE SHIFT
CREW WORK TIME (HR) (AXAF RELATED)	18	21	INCLUDES ORBITER BOOST OF AXAF TO OPERATING ALTITUDE
EVA TIME (HR)	11	11	
COSTS, MILLION (1984 DOLLARS)	$16.3	$63.4	ORBITER RESUPPLY FLT TO SOC COSTS INCLUDED
CONTINGENCY, MILLION (1984 DOLLARS)	$0.09	$2.0	ONE DAY WITH 2 EVAs

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Fig. 3.3-10 Comparison of AXAF Servicing From Space Station & Orbiter

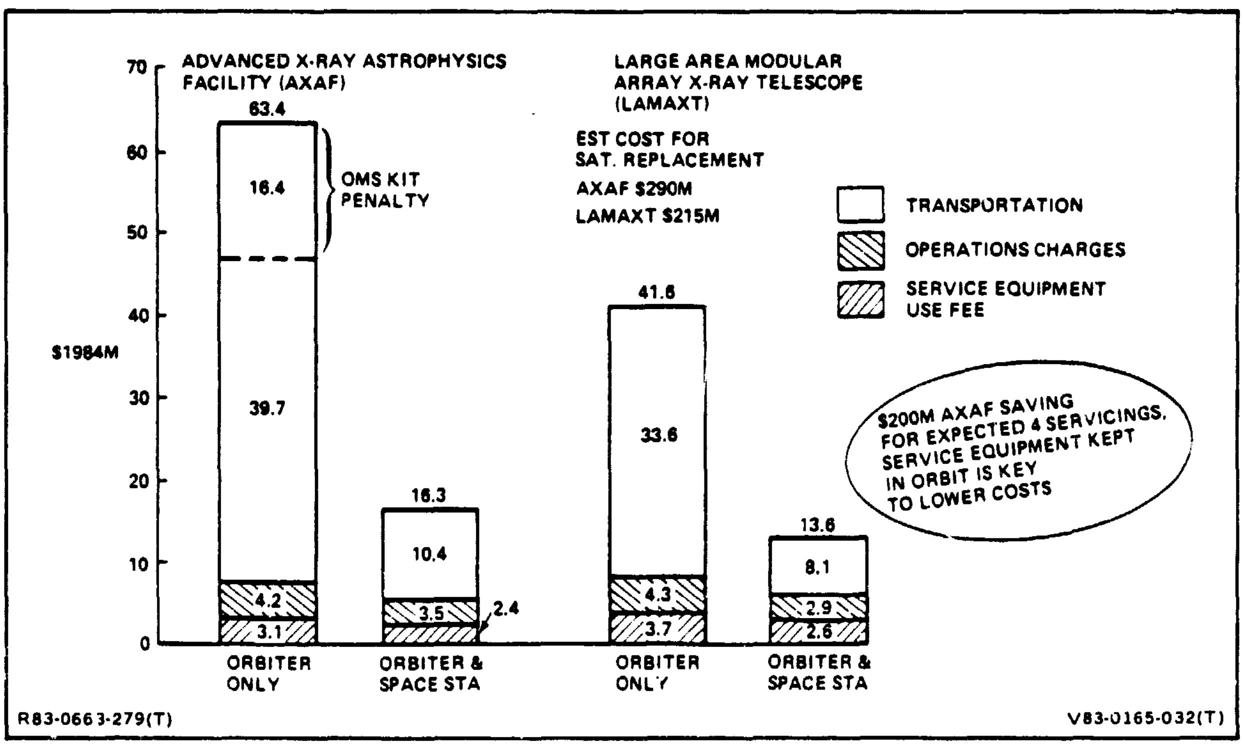

Fig. 3.3-11 Revisit Service Costs

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COST CATEGORIES	1984 CONSTANT $M	
	ORBITER ONLY	ORBITER & SPACE STATION
TRANSPORTATION		
• ORUs, INSTRUMENTS, POM, HPA	39.7	
FLUID TRANSFER, EQPT, CMG RACK, OMS KIT	16.4	
• ORUs, INSTRUMENTS, TMS FUEL, DOCKING MODULE		10.4
OPERATIONS CHARGES		
• POCC PROCEDURES DEVEL, PAYLOAD SPECIALIST TRAINING, PAYLOAD REVISIT, TDRSS USE, KSL FLOW IMPACT	2.1	2.1
• ORBIT SUPPORT	1.6	0.5
• CREW OPERATIONS	-	0.7
• CREW EVA	0.5	0.2

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Fig. 3.3-12 AXAF Revisit Service Costs (Sheet 1 of 2)

COST CATEGORIES	1984 CONSTANT $M	
	ORBITER ONLY	ORBITER & SPACE STATION
SERVICE EQUIPMENT USE FEE		
• SECOND RMS, HPA, OCP	0.5	0.5
• PALLET	1.7	0.9
• OMS KIT	0.2	-
• POM	0.6	-
• TMS	-	0.9
• AFD CONTROLS & DISPLAYS	0.1	-
• DOCKING MODULE	-	0.1
TOTAL	63.4	16.3

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Fig. 3.3-12 AXAF Revisit Service Costs (Sheet 2 of 2)

scale), while orbiter alone operations meet the needs of the individual payload(s) to be deployed, serviced or retrieved, and are forced by other considerations to operate with less than maximum cargo capability.

For budgetary purposes, the cost of replaceable equipment necessary to service the AXAF was determined. The ratio of the weight of the replaced equipment to the total weight is 6%. This factor is applied to the then year costs for the spacecraft, giving equipment costs.

3.3.2 Solar Terrestrial Missions

Candidate Space Station missions are listed in Fig. 3.3-13 for externally mounted payloads and free flyers. Figure 3.3-14 contains sketches of some of the externally mounted payloads and Fig. 3.3-15 lists the documentation resources. Descriptive information about potential internal and external mounted Space Station payloads follow in subsequent subsections. The free flyer missions interface with the Space Station is to mate upper stages for transportation to their operational orbit and/or service them at the required interval.

3.3.2.1 Solar Optical Telescope (SOT) & Advanced Solar Observatory (ASO) - (GRUM 0224 & GRUM 0225) - The first mission listed in Fig. 3.3-13, SOT will be operated from the orbiter during sortie missions then transferred to Space Station when it becomes operational in 1990. After several years' operation, the telescope will be returned to earth and upgraded to the Advanced Solar Observatory (ASO) configuration.

The SOT is a multi-user, facility-class telescope with an aperture diameter of 1.25 m which will give diffraction-limited resolution of 0.1 arc-sec and at 5500 A (72 km on the sun; less than one scale height). It operates from 1100 A to 11,000 A and thus can observe solar phenomena from the low photosphere up through the chromosphere and transition region to the base of the corona. In its "basic" form, the SOT focal plane instruments will include narrow-band filters, polarimeters and high-resolution spectrographs. This basic SOT has been studied extensively and is a serious candidate for development as a facility-class instrument for operation on the Spacelab. However, a more highly evolved, "full-up" version of SOT (ASO) has also been proposed for Spacelab operations, which would impose heavy demands because of greater weight and power requirements. If a Space Platform becomes

II/1/I

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	EXTERNAL PAYLOADS				
[illegible]	SOLAR OPTICAL TELESCOPE (SOT)	88	90	460	SOLAR
0225	ADVANCED SOLAR OBSERVATORY (ASO)	92	57-90	400-460	SOLAR
0226	SOLAR TERRESTRIAL OBSERVATORY (STO)	94	90	450	SOLAR, EARTH, LIMB & NADIR
0227	RENEWABLE RESOURCES PAYLOAD (RRP)	93	60-90	705	EARTH, NADIR & OFF NADIR
0228	GEOLOGY PAYLOAD (GP)	96	90	705	EARTH
0229	CRUSTAL DYNAMICS STUDY	90	50	450	EARTH, NADIR & OFF NADIR
0230	AURORAL MANNED OBSERVATION PLATFORM	90	65-90	400	EARTH
0232	SOIL & SNOW MOISTURE RESEARCH & ASSESSMENT	90	60	465	EARTH

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Fig. 3.3-13 Solar Terrestrial Missions (Sheet 1 of 2)

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM– 0233	ADVANCED THERMAL MAPPING APPLICATIONS	90	57	400	EARTH
0234	MULTIDISCIPLINE ADV LAND OBS SYSTEM	92	POLAR	400	EARTH
0235	EPISODIC EVENTS DETECTION (EED)	97	POLAR	400	EARTH
0236	ADVANCED EARTH RESOURCE SENSING SYSTEM	90	57	400	EARTH
	FREE FLYER MISSIONS				
0350	ORIGIN OF PLASMA IN THE EARTH NEIGHBORHOOD ("OPEN")	90	28.5	N/A	MULTIPLE
0351	SUBSATELLITE FACILITY	90	ANY	ANY	MULTIPLE
0352	STARPROBE	92	60°	N/A	SOLAR
0353	SOLAR INTERIOR DYNAMICS MISSION (SIDM)	89	28-98	5.75	SOLAR
0354	ADVANCED INTERPLANETARY EXPLORER (AIE)	94	28.5	L_1	SOLAR
0355	SOLAR CORONA EXPLORER (SCE)	87	33	600	SOLAR

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Fig. 3.3-13 Solar Terrestrial Missions (Sheet 2 of 2)

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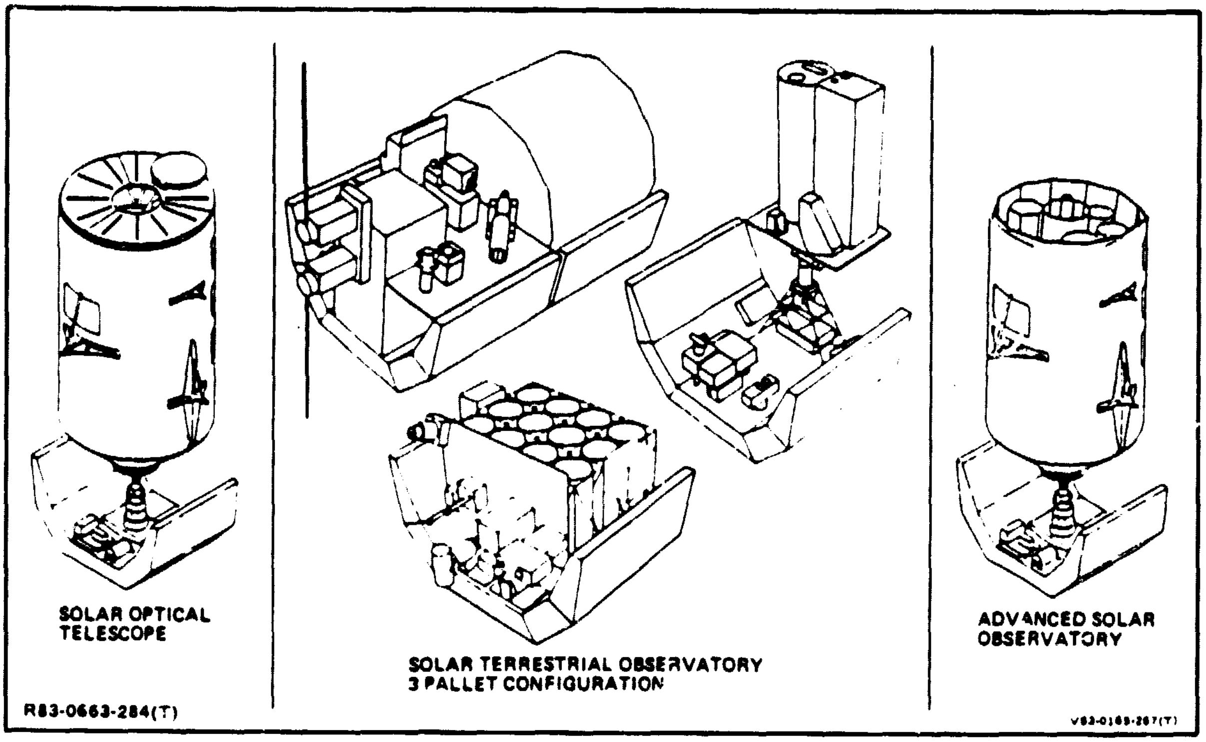

Fig. 3.3-14 Solar Terrestrial External Payloads (Sheet 1 of 2)

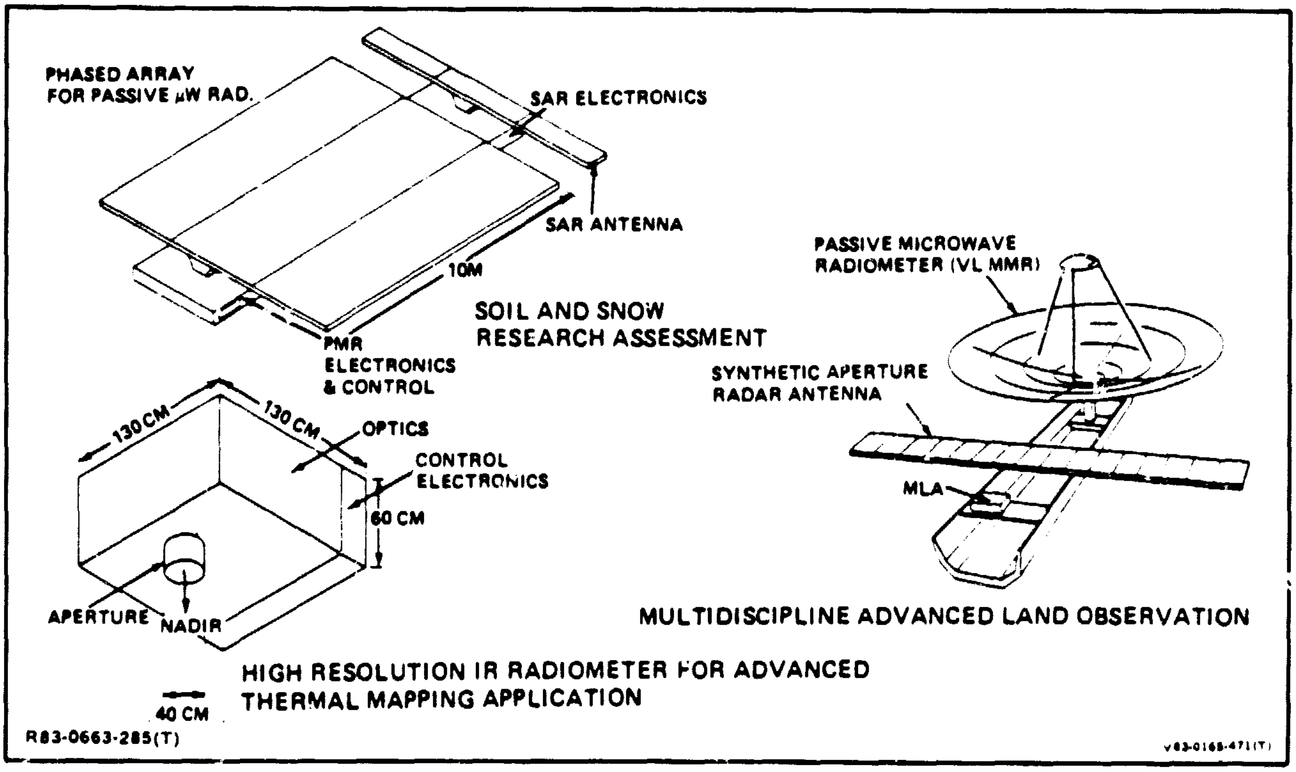

Fig. 3.3-14 Solar Terrestrial External Payloads (Sheet 2 of 2)

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ID NO.	MISSION/ PAYLOAD	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES					
		UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–	EXTERNAL PAYLOADS						
0224	SOLAR OPTICAL TELESCOPE	P-83		S-6		PAGE A-56	PAGE 20
0225	ADVANCED SOLAR OBSERVATORY	P-84				PAGE A-67	PAGE 20
0226	SOLAR TERRES-TRIAL OBSERVATORY	P-90 & 115		S-24		PAGE D-57	
0227	RENEWABLE RE-SOURCES PAYLOAD						PAGE 53
0228	GEOLOGY PAYLOAD						PAGE 64
0229	CRUSTAL DYNAMICS STUDY			R-5			PAGE 67
0230	AURORAL MANNED OBSERVATION PLATFORM		NEW MISSION CONCEPT				
R83-0663-286(T)							V83-0165-107(1/2)(T)

Fig. 3.3-15 Solar Terrestrial Missions Documentation (Sheet 1 of 2)

ID NO.	MISSION/ PAYLOAD	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES					
		UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM– 0232	SOIL & SNOW MOIS-TURE RESEARCH & ASSESSMENT			R-10			
0233	ADVANCED THERMAL MAPPING APPLICA-TIONS			R-7			
0234	MULTIDISCIPLINE ADVANCED LAND OBSERVING SYSTEM		NEW MISSION				
0235	EPOSODIC EVENTS DETECTION						PAGE 68
0236	ADVANCED EARTH RESOURCE SENSING SYSTEM		NEW MISSION				
R83-0663-287(T)							V83-0165-107(2/2)(T)

Fig. 3.3-15 Solar Terrestrial Missions Documentation (Sheet 2 of 2)

available in the 1990s, it may be better equipped to provide these support requirements of the ASO than Spacelab.

All of the science problems for SOT share two features: (1) They are different aspects of determining the temperature, density, states of ionization and excitation, non-thermal velocity and magnetic field of the solar plasma as a function of surface position and time from the low chromosphere to the base of the corona, with sufficient resolution to permit definitive studies of the transport of energy and mass from the solar convection zone into the corona and beyond; and (2) They are problems which can be addressed with the payload of the basic SOT, though in some cases the problems require, ideally, more observing time than early Spacelab missions will provide. When the full complement of instruments planned for the ASO is flown, an even longer list of problems encompassing coronal physics can be resolved.

A number of requirements of the full-up SOT are, at best, just met by the currently baselined Spacelab. These fall into the general categories of weight, power, telemetry rate and, most important of all, duration for required observations. In general, when the event to be studied is comparatively rare, when good statistics are needed, or when the solar features evolve slowly in time, extended observing time is required.

3.3.2.2 Solar Terrestrial Observatory (GRUM 0226) - The STO payload consists of approximately 25 experiments that include solar telescope, earth atmosphere remote sensors, particle and field sensors, and particle and wave injectors and free flyers-subsatellite recoverable plasma diagnostic package and chemical release module. Many of the instruments are separately controlled and pointed to the sun, earth nadir and earth limb.

The Space Station STO will yield a better integrated and/or more complete STO with less downtime and greater operational flexibility than would be the case for a non-Space Station STO. The manned Space Station will allow better STO response to unanticipated solar and/or magnetospheric conditions that are particularly suitable for conducting magnetospheric experiments and also for observing special magnetosphere/ionosphere/earth atmosphere effects. The manned presence of a Space Station STO will also result in better mission reliability in terms of much shorter

downtime as the result of a failure or depletion of consumable. The Space Station can carry consumable replenishment as well as spare components or submodules for those considered most likely to fail. The constant presence of a crew with EVA capability will then permit the relatively rapid return of the STO to operational status.

Of course, any STO mission which is Space Station-mounted will have most of its basic services supplied by the Space Station (electric power, data storage, computer capabilities, and communications to ground either direct or via TDRSS), and as such will result in a significant mission cost savings as compared to any self-supporting free flying non-Space Station mission design. All of the above considerations mean higher STO mission effectiveness at lower cost if the mission is part of a manned Space Station.

3.3.2.3 Renewable Resource Mission (GRUM 0227) - The RRM is similar in approach to the STO in that a number of instruments (approximately 10) make up the payload. These instruments look at earth nadir, scanning across track and in the direction of flight and some instruments view earth limb, to provide the following capability:

- **Vegetation Sciences Research** - This discipline is to increase the fundamental understanding of the biophysical and biochemical processes which affect the land surface of the earth, in order to better interpret and use remotely-sensed data for the solution of food and fiber resource problems. The Space Station could provide opportunities for extended observational opportunities from satellite orbital altitudes. Such observations virtually guarantee coverage of the entire vegetated land surface of the earth and guarantee observations over a variety of viewing conditions. The Space Station approach offers two additional advantages
  - The opportunity to fly a full range of instruments which simultaneously view the same surface areas
  - The opportunity to alter instrument parameters and/or repair instruments through man-tending
- **Vegetation Resources Inventory and Monitoring** - Currently, uncertainties of several-orders of magnitude exist in the estimates of the total amount vegetative matter (biomass) on the surface of the earth. This uncertainty exists because the real extent and distribution of vegetative units (biomes)

has not been measured, let alone monitored for changes over time. It is important that the current number of bronies in each biome be determined because the relationship of number and degree of change influences weather and climate trends. The Space Station could provide the capability to acquire these long-term, near-global observational data for measuring the earth's food and fiber resources. With an appropriate choice of orbital parameters, the Space Station offers the advantage of acquiring the observational data at the temporal frequency necessary for input to models used to forecast agricultural production and yield, for input to the decision process for rangeland utilization and for input for managing timber harvests

- **Land Cover Dynamics Research** - Mankind is currently altering the nature of natural land cover through such direct actions as urbanization, industrialization and deforestations; through such indirect actions as ranchland overgrazing which can lead to desertification of the land; and disposal of waste materials which can seep into the ground and lead to pollution of the water. Scientific studies have demonstrated that the scale of human activity is clearly sufficient to alter the land environment on regional scales and it is only a matter of time before these scales reach continental and eventually global proportions. These changes could result in alterations to global atmospheric circulation patterns, precipitation and land productivity. The global extent of these man-induced changes have not been quantified, nor has the ability of natural systems to adjust to the changes or recover from past changes, been studied so that projections of future habitability of the planet can be made. The Space Station could provide the opportunity to fly both low and high resolution multispectral instruments to provide data for both survey and detailed studies. An appropriately instrumented Space Station could also obtain global data for extended periods of time from which secular and seasonal changes could be separated from long-term changes in the land cover. In addition, atmospheric and hydrologic data could be acquired from the complement of instruments on the Space Station supporting other disciplines to indicate impact of land cover changes on those physical systems
- **Hydrologic Cycle Research** - Because of its impact on the vegetative and atmospheric physical systems, a basic requirement exists to develop knowledge and understanding of the earth's hydrologic system, particularly the hydrologic cycle. For example, soil moisture is a crucial parameter which

affects agricultural production and energy balance of the earth's surface. A given soil moisture value results from the interaction of precipitation, evaporation and runoff processes. Evaporation affects the moisture content of the atmosphere, which, in turn, affects weather and climate predictions. Evaporation also provides the moisture resource in the atmosphere for precipitation to occur, thus closing the cycle. Techniques using measurements in the microwave region of the EM spectrum, taken on the ground and from aircraft, have been developed to study soil moisture processes and interactions. These techniques have been applied successfully to local regions. But the nature and dynamics of worldwide soil moisture processes and the distribution and magnitude of precipitation and evaporation processes over land and water areas needs to be studied. For this purpose global data sets over time are needed. Instrumentation placed on a Space Station would be able to measure parameters associated with the hydrologic cycle on a global scale, and provide the repeat visit frequency that is essential for detailed quantitative studies.

- **Water Resources Inventory & Monitoring** - The world's water resources available for personal, agricultural and industrial/commercial use resides in underground acquifers, reservoirs, lakes and rivers, which are replenished directly through precipitation and indirectly through snowmelt runoff in high latitude areas. Uncertainty exists in regional and even subcontinental estimates of the supply of water that is or will be available for man's use because of uncertainty in a real extent and condition (such as pollution) of water equivalency of snow cover. The Space Station will provide the platform to collect observational data needed to further develop and refine remote sensing techniques necessary to quantify the volume of water available for use and long-term trends in its condition. The large mounting area on this spacecraft offers the advantage of being able to simultaneously fly several different types of instruments to provide the varied measurements required to study water resources states and conditions.

3.3.2.4 Geology Payload (GRUM 0228) - Monitoring the earth's resources from space is far more economical and practical than conventional methods using airplane and ground surveys. Although many of the details of determining the characteristic signatures of rock units are still being developed, several advantages of spaceborne resource monitoring are already apparent.

The most important advantages are:

- Wide coverage over short periods of time
- Short revisit cycles
- Examination and development of inaccessible areas
- Flexible instrument designs.

The goal of geology is to acquire sufficient information on composition, structure and chronology to reconstruct the geologic evolution of an area. Remote sensing is particularly useful for determining structure and lithology. By the advent of the Space Station in the early 1990s, we will have learned how to use the visible and infrared imagery obtained by Landsat to discriminate and identify rock units and map surface structure. Significant advances in radar remote sensing will have been made toward understanding the effect of variable incidence angles, wavelengths and polarizations on the interpretability of orbital radar imagery. The next step will be to combine these two types of data in a controlled manner (registered and calibrated) to determine what geological information can be obtained from the combined data sets. In order to pursue these studies, the diverse data sets must be acquired simultaneously or near-simultaneously since data acquired at different times have additional variables such as surface temperature, soil moisture and vegetative cover, thus making comparisons extremely difficult. The advantage offered by the Space Station is its capability of supporting many large instruments so that data may be acquired over a particular area simultaneously with all instruments.

3.3.2.5 Crustal Dynamics Studies (GRUM 0229) - A number of rapid and potentially dangerous phenomena may also be studied by remote sensing methods. These include volcanism, landslides and rapid tectonic deformations or crustal dynamics. This area in particular is exciting because of the dearth of information available today and because of tantalizing hints that a Space Station could play a significant role in refining our concept of global rock distribution and geologic structures, and also in detecting or monitoring geodetic changes.

Measurements of crustal deformations can provide information on stresses within the earth, the interior rheology and subsurface structure. Within the context of tectonic plate theory, they provide information on the driving mechanism for plate motions and assessing plate rigidity. On a regional scale, geodetic measurements can provide information on the accumulation of strain in seismically active regions.

Geodetic measurements provide information on spatial and temporal patterns ranging from several months to decades. Crustal deformation can be interpreted in terms of tectonic plate motion, strain accumulation and release and other horizontal and vertical motions. This study will provide data needed for fundamental theoretical and computational studies of both earthquakes and other processes that deform the earth's surface, which are necessary to provide a framework for interpreting geodetic measurements and for modeling the underlying physical processes.

3.3.2.6 Auroral Manned Observation Platform Experiment (GRUM 0230) - The mission objective is to provide both broad-view observation of nightside auroral phenomena (both northern and southern hemispheres) and selected detailed examination of various auroral features. This observation experiment utilizes a trained auroral scientist's selection of appropriate camera/other imaging systems. It can be part of a coordinated scientific effort using the Origin of Plasma in the Earth's Neighborhood (OPEN) GRUM-0330 system of four satellites that are tentatively to commence operation in the late 1989-1990 time-period.

Because visual aurora features can be rapidly fluctuating as a function of time (from seconds to minutes to hours) and position across the auroral zones, the advantage of having a trained orbiting scientist observing in real-time to direct imaging systems at features of interest is obvious. While similar observations can be made by a Spacelab/STS scientist, the Space Station observer, who could be viewing for 90-day mission durations, would likely observe a far more complete range of features from various intensities of auroras than would be possible from a typical seven-day Spacelab mission. In addition, locating the experiment on the Space Station would allow for easy access for change of camera film and instrument repair/recalibration.

3.3.2.7 Soil, Snow, Moisture Research & Assessment (GRUM 0232) - This mission will provide synoptic and repetitive measurement of moisture content of soils. Its end use will be for agriculture, water resource and climate analyses. There will be a capability for mapping and specific observation of selected areas.

Proper assessment of agricultural production is strongly dependent on: (1) knowledge of the availability of moisture within the soils under cultivation, and (2) the soils that drain into them. The quantity of moisture present within the soil

also effects the availability of runoff for other purposes and reflects the subsurface water content.

This mission will provide fundamental data regarding the availability of a critical resource already in short supply. Commercial demand for data on specific sites is expected to become significant in the next decade and beyond.

The Space Station is important for this mission because of the advantages it provides in assembly and operation. Large structures such as the antennas to be used on this mission can be erected by a large Space Station crew with relative ease. The flexibility of having an on-site operator also makes response to commercial requirements practical. Remote operations would require a far more expensive and sophisticated system.

3.3.2.8 **Advanced Thermal Mapping Applications (GRUM 0233)** - The mission objective is to obtain a thermal infrared resource survey useful to the fields of geology, geophysics, agriculture, forestry, land use and water resources. The mission duration would nominally be for one year, with extensions for missed coverage as required. The experiment package, which could be mounted externally on the initial Space Station, would use the results/recommendations derived from earlier Shuttle developmental testing involving multiband thermal imagers.

Space Station implementation costs are lower than those for Spacelab/STS and significantly lower than those for a satellite mission. Spacelab/STS requires several flights for adequate earth coverage, which would result in launch costs that are much greater than those for a Space Station mission.

3.3.2.9 **Multidiscipline Advanced Land Observing System (GRUM 0234)** - This mission will provide image information that can be used to determine mineralogical structure, morphology, surface cover characteristics, vegetation and crop condition. Other parameters that will be addressed are water, temperature and humidity. A significant number of users purchase analyses based on evaluation of the characteristics of such remote imagery (e.g., General Electric GEOPAK), usually in the form of statistical evaluations of the probability of occurrence of certain deposits or crop yield. Some users buy the digitally enhanced imagery or special photo

products made by combining imagery derived from more than one instrument such as the SAR/SAT imagery offered by Aero-Service.

The criticality of knowledge of and planning for world-wide resource and food production and the economic and human description that their neglect can create is self-evident. This mission provides an analytical source of information far in excess of that planned by any of the industrialized nations and so becomes a unique and powerful tool.

Assembly of such a large and complex system would be very difficult using anything smaller than the Space Station as a staging area. The number of men involved would be more than the Shuttle could provide. Similarly, operation and data management would tax a ground-based approach, and maintenance using the Shuttle alone would require too many trips.

3.3.2.10 Episodic Events Detection & Assessment (GRUM 0235) - Disaster management encompasses a number of man-induced and natural disasters, including floods, landslides, earthquakes, volcanic eruption, insect and disease infestation, drought, forest/range fires and oceanic oil spills. Activities include the initial detection and identification of the event, short- and long-term monitoring of the event and its consequences, environmental impact assessment and baseline research studies in support of the disaster. The activity phases for any particular event involve differing sensor needs (i.e., spectral bands, spatial resolution), and varying platform requirements (frequency of observation, aerial coverage, stereo capability).

Satellites perform a complementary role to field surveys, aircraft reconnaissance and ground data collection in obtaining information regarding disaster assessment. However, episodic events are unique in that the disaster region is frequently characterized by inaccessibility and/or poor visibility due to clouds, haze and smoke. In many cases, satellite imagery is the only information available for assessment activities. Most satellite systems currently in existence are not suitable for disaster management applications; it is imperative that Space Station utilization include sensors optimized for the observation of man-induced and natural disasters.

The instruments are similar to those for Renewable Resources Payload (GRUM 0227), but with the additional capability of a bore-sighted optical system with many

sensors slaved to it and the on-board capability of changing spectral and spatial resolutions of instruments.

3.3.2.11 Advanced Earth Resources Sensing System (GRUM 0236) - This mission will act as a successor to the Landsat D series of spacecraft. It will provide high resolution imagery in the visible and IR with an integrated sensor system and consequently will support a wide-range of geological and agricultural missions.

The emphasis will be upon a flexible response to user requirements. It will provide many bands of interest on demand through the manipulations of the technician aboard the Space Station who is operating the instrument. The instrument itself will be designed for maximum reliability and minimum development risk.

The Space Station provides the first practical means for operating a truly flexible instrument in space. Direct operator control from the shirt sleeve environment of the Station is contemplated. Remote operation would require complexity that would defeat the requirements on reliability and cost. With the sensor end of the instrument extending within the Station, a human operator can vary filters, pointing and other system parameters at will so long as he has the requisite equipment. Since another filter or detector is likely to be small and light, it can be brought up on the next Shuttle flight.

Since this instrument is a single integrated unit, it can be easily transported to the Space Station and mounted with relatively low cost; certainly the cost would be less than the design and construction of an independent spacecraft. The instrument could be tested, calibrated and modified in place, reducing the likelihood of failure.

The large data rate contemplated would also benefit from the presence of a trained operator. He could provide on-board analysis of data qualities and evaluations of image significance before transmission to earth.

3.3.3 Global Environment Missions

Candidate Space Station missions are listed in Fig. 3.3-16 for internally mounted and externally mounted payloads. Six free flyer missions have also been included in the figure. Figure 3.3-17 contains sketches of some of the payloads,

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	INTERNAL PAYLOAD				
0125	ATMOSPHERIC GEN CIRC EXPERIMENT	93	ANY	ANY	N/A
	EXTERNAL PAYLOADS				
0250	METEOROLOGICAL PAYLOAD	91	98	400	EARTH
0251	ATMOSPHERIC RESEARCH PAYLOAD (ARP)	90	64-90	500	SOLAR, EARTH, NADIR & LIMB
0252	TROPICAL METEOROLOGICAL SUPPORT	94	28.5	400	EARTH
0253	IMAGING RADAR EXPERIMENT (FIREX)	89	90	800	EARTH
0254	OCEAN PAYLOAD	91	98	300	EARTH
0255	LIDAR MEASUREMENT OF AIR QUALITY	89	75	500	EARTH
	FREE FLYERS				
0374	LOWER ATMOSPHERE RESEARCH SAT. (LARS)	90	60-92	780	EARTH
0375	GEO OPERATIONAL ENVIRONMENT SAT FOLLOW-ON	91	0	GEO	EARTH
0376	ADV OP METEOROLOGICAL SYS (METSAT)	90	98	833	EARTH
0377	OCEAN CIRC MISSION TOPOGRAPHY EXP (TOPEX)	90	65	1300	EARTH
0378	WINDSAT	93	90	400-800	EARTH
0379	UPPER ATMOSPHERE RESEARCH SAT. (UARS)	88	70	500	EARTH

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Fig. 3.3-16 Global Environment Missions

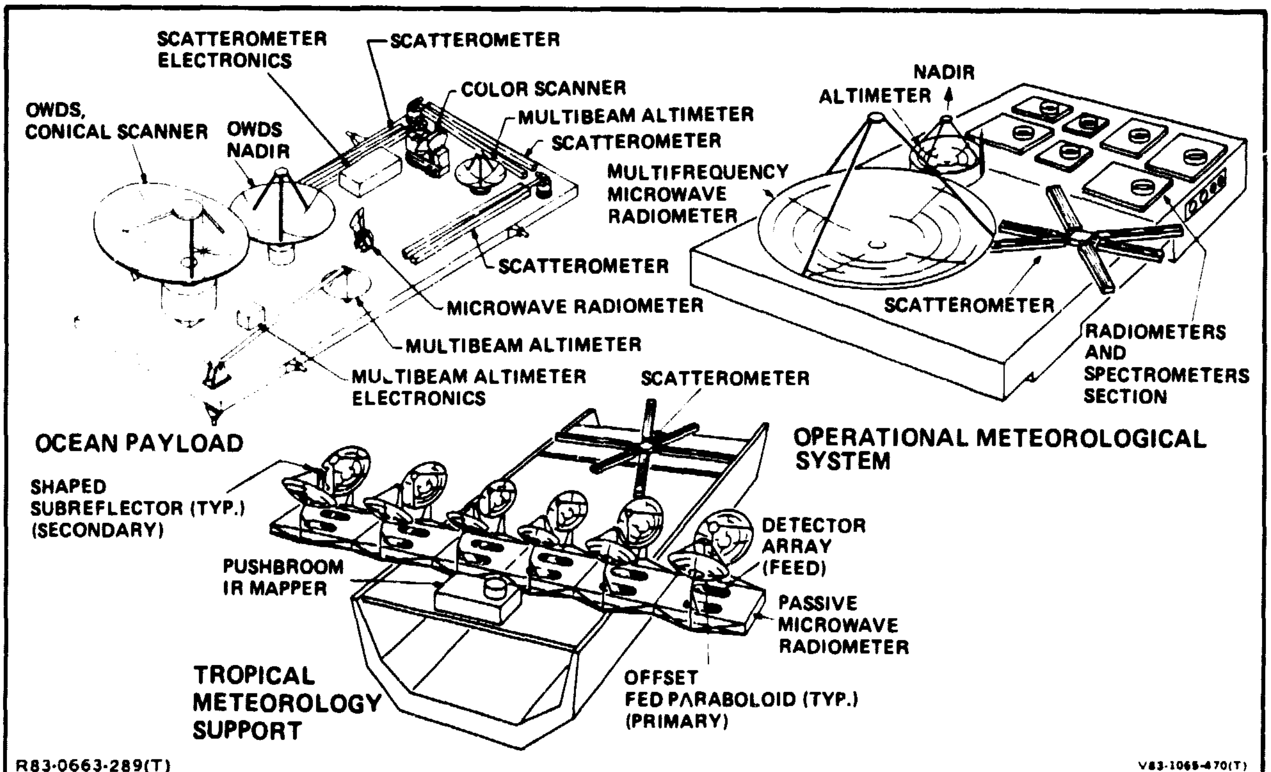

Fig. 3.3-17 Global Environment External Payloads

and Fig. 3.3-18 lists documentation resources. Descriptive information about potential internally and externally mounted Space Station payloads follow in subsequent subsections. The free flyer mission interface with Space Station would be to mate upper stages for transportation to their operational orbit and/or service them after the required interval of operation.

3.3.3.1 Atmospheric General Circulation Experiment (GRUM 0125) - The AGCE mission objective is to experimentally model the large-scale circulation of the earth's atmosphere in hemispherical geometry. The facility will be rack mounted in a pressurized shirtsleeve environment. The working fluid, which will simulate the atmospheric motions, will be held between two concentric spheres, and subjected to a radial electric field in the form of the spherical capacitor. The electric field acting on the high dielectric constant fluid will simulate the earth's gravitational force on the atmosphere. A representative pole-equator temperature gradient and the large-scale vertical stability of the atmosphere will be modeled by maintaining latitudinal temperature gradients on the spheres and by maintaining the outer sphere warmer than the inner sphere. Earth's rotation will be modeled by corotating the spheres.

There are two alternatives for implementation of the AGCE: (1) on a series of Shuttle/Spacelab flights; or (2) in a Space Station. The obvious choice is to use the Space Station since the frequency and schedule of experiment cycles can be dictated by the scientist's analysis and interpretation of the experiment results rather than by the flight schedule of the shuttle/Spacelab. This should result in a shorter duration program and a more rapid disemination of the results to the scientific community. In addition, use of Space Station will eliminate the need for frequent and costly requalification of the experiment facility as would be required on a series of shuttle flights.

3.3.3.2 Advanced Operational Meteorlogical (METSAT) Payload (GRUM 0250) - The polar METSAT mission requirements for the 1990s will be the same as for the present Tiros-N. Tiros-N, the prototype satellite system and its operational follow-on satellites, is designed to provide an economical and stable platform for the advanced instruments to be used in making measurements of the earth's atmosphere, its surface and cloud cover, and the proton and electron flux near the earth. As a part of this mission, the satellites also have the ability to receive, process and

11/1/1

ID NO.	MISSION/ PAYLOAD	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES					
		UAH/ NASA WORK-SHOP 9/78	PROJECT CON-CEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMTS (DRAFT) 11/82
GRUM–	<u>INTERNAL PAYLOAD</u>						
0125	ATMOSPHERIC GENERAL CIRCULATION EXPERI-MENT		NEW	MISSION			
	<u>EXTERNAL PAYLOADS</u>						
0250	METEOROLOGICAL PAY-LOAD					PAGE D-1	PAGE 41
0251	ATMOSPHERIC RESEARCH PAYLOAD		NEW	MISSION			
0252	TROPICAL METEORO-LOGICAL SUPPORT						PAGE 77
0253	IMAGING RADAR EXPERIMENT			E-8			
0254	OCEAN PAYLOAD			E-6		PAGE D-7	PAGE 79
0255	LIDAR MEASUREMENT OF AIR QUALITY		NEW	MISSION			

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Fig. 3.3-18 Global Environment Missions Documentation

retransmit data from free-floating balloons and buoys and remote automatic observation stations distributed around the globe, and to track those stations which are in motion.

The Space Station could incorporate the instruments of one of the polar orbiting operational meteorological satellites and thereby replace that satellite. Another role would be to service meteorological free flyer satellites.

3.3.3.3 Atmospheric Research Payload (GRUM 0251) - This mission is a combination of Lower Atmospheric Research Satellite (LARS) and Upper Atmospheric Research Satellite (UARS) programs. It is expected that UARS will have flown before Space Station flights, but that more data from at least some of the instruments will be needed. Results from the UARS mission (1988 launch) could be used to select key instruments for this mission. Orbital parameters for LARS and UARS are similar enough to permit their using the same platform with the advantage of the coupl[illegible] of data interpretation. This mission will have high scientific value. Result [illegible] e used to understand many of the problems affected by the atmosphere and will ultimately have considerable socio-economic value. It is likely that results from some instruments will indicate that they are needed as constant monitoring instruments in future operational missions. The large surface, weight and power capability of Space Station are advantageous. On-orbit replenishment of cryogenic would increase the lifetimes of several instruments. The crew would be used to perform onboard calibration and to make changes in payload configuration which can be expected to be both planned and unplanned. It is not expected that all the instruments will be carried at once. While they will each be carried for substantial times (probably a year or more), there will be replacements, both with improved versions of the same instrument and with totally different instruments designed to accomplish totally different objectives. The instruments will be mounted on an unpressurized pallet or platform and control electronics will be placed in the pressurized compartment so that the crew can monitor and control the instruments. Ongoing technological developments of some instruments which will cause them to be different than those currently projected may make it advisable to change some instruments during the mission. The crew will service the instruments as necessary (i.e., replenish cryogens).

3.3.3.4 Tropical Meteorological Support Mission (GRUM 0252) - The objective of this mission is to perform environmental measurements of the equatorial belt (from approximately +30 deg N to 30 deg S) that will support the global meteorological measurements needed in climatological and weather investigations.

The equatorial regions (particularly the oceanic areas) have a large influence in the development of global weather patterns. The users (scientists as well as operational meteorologists) can make use of frequent and accurate data on vertical profiles of parameters such as atmospheric temperature, water vapor content and precipitation. These measurements, coupled with surface temperatures and wind vectors, will provide useful supplementary data to better understand the heat and mass exchange mechanisms as well as dynamic phenomena encountered in the equatorial belt and their effect on global weather.

This mission was considered as a promising candidate due to this high value in scientific and operational meteorology; use of the astronaut in the deployment of a large antenna assembly and in the maintenance, reconfiguration and control of the payload; and feasibility in a low inclination, low altitude orbit.

3.3.3.5 Imaging Radar Experiment (GRUM 0253) - The primary objective of the mission is to use a Synthetic Aperture Radar (SAR) to: (1) provide information on the status of sea ice in ocean shipping lanes; (2) assess the utility of SAR imagery in providing information relative to renewable and nonrenewable resources; and (3) provide area mapping of oceanographic features using the demonstrated capabilities of SAR and investigate the utility of SAR to other areas of oceanography. A mission concept for ice processes was defined in a GE study performed under NASA Contract NAS-5-23411, Mod 47, titled, "Feasibility Study, Radar for Ice Properties and Climate (IPAC) Studies." A comprehensive definition of other mission objectives can be found in a NASA/JPL document titled "Science Requirements for Free-Flying Imagery Radar (FIREX) Experiment."

The mission should be continued daily over a period of years since:

- Images of shipping lanes in sea ice have commercial impact
- Sea ice extent together with oceanographic features should be valuable for long range weather forecasting

- Identification, area estimation and condition assessment of major agricultural crops will be valuable for annual crop production estimates.

The SAR would be installed on a Space Station carrier and launched to the Space Station by the STS where the SAR/carrier would be attached to the Space Station. The SAR would then be operated over ocean ice and land areas for up to five years. In normal operation, the crew would make significant hardware configuration changes such as:

- Replacing antennas differing in frequency band (i.e., L-band, C-band, X-band)
- Re-orienting a rectangular antenna aperture from horizontal to vertical.

For maintenance, the crew can be involved to replace (or repair) defective "boxes" such as the radar transmitter.

Seasat demonstrated the potential value of SAR in ocean research. The Imaging Radar Experiment will be an extension of the Seasat-SIR-FIREX missions into the 1990s, using the Space Station as the base of operation. The mission addressed here is in the Science/Applications category, although there will be significant potential applications for the data in areas such as navigational aids and providing complementary data to commercial weather forecasting and mineral exploration organizations. For example, the estimated economic benefit of the RADARSAT to Canada is $90M to $150M per year by 1990 and $110M to $180M per year by 1994 through reduced shipping time, reduced operating and maintenance costs, as well as reduced costs relating to shipping hazards.

A summary of mission implementation costs is given in Part II for the three mission options. Space Station mission implementation costs are lower in all categories except labor, where significant on-orbit technician involvement is assumed throughout the five-year mission life.

3.3.3.6 Ocean Payload (GRUM 0254) - The broad objective is to develop spaceborne techniques and to evaluate their utility for observing the oceans. Specifically, the aim is to determine the circulation, heat content and horizontal heat flux of the global oceans, how they are influenced by the atmosphere and how they influence climate; to determine the primary productivity of the oceans, how it is influenced

by ocean circulation and the atmosphere, and how it in turn influences the marine food chain, the rate of CO_2 uptake by the oceans, and climate. The third area of interest is the determination of the characteristics of the polar sea ice cover, how they are influenced by the atmosphere and the ocean, and how they in turn influence climate.

In order to accomplish these objectives, we need to obtain several global oceanic data sets of long duration, typically three to five years. This mission complements TOPEX, the only free flyer currently being proposed in support of the Oceans Program.

The Space Station would be a useful platform for the deployment and operation of ocean sensors such as the Scatterometer, the Ocean Color Imager (OCI), Synthetic Aperture Radar, and passive microwave radiometer (possibly using a large dish antenna for high resolution Sea Surface Temperature). Additionally, the Space Station would make an excellent platform for the check-out and evaluation of new ocean instrument techniques such as those proposed in the Ocean Microwave Package.

In terms of specific ocean investigations more closely related to the Space Station, the following are worthy of consideration:

- The ability to quantify patterns and variability of phytoplankton chlorophyll from satellites using ocean color sensors presents an opportunity to reduce our uncertainties in the rate of marine productivity and biogenic sequestering of carbon dioxide by an order of magnitude
- The Space Station could be used to develop and deploy other sensors providing additional capability, such as night bioluminescence detectors as indicators of krill and fish activity, both active and passive chlorophyll fluorescence sensors and large area microwave devices required for fine spatial resolution sensing of physical properties. The key here is the human element again
- Third, and most exciting, would be the insights gained into the spatial organization of marine systems by an astute observer knowledgeable in ocean and, especially, plankton dynamics. The Space Station will be over oceans for 70% of the time, and ocean color related features are readily observable, as indicated by Skylab and Apollo astronauts.

3.3.3.7 Lidar Measurement of Air Quality (GRUM 0255) - The mission objectives are to measure secondary and trace gas atmospheric species and their world-wide distribution from relatively low altitudes to as high as 100 km. Other objectives include the vertical and horizontal distribution of atmospheric temperature, pressure, aerosol (haze) layers and cloud top heights. Eventually, wind measurements should also be possible.

While no one lidar system has yet been used in space or for all the abovementioned measurements (from one system), various ground- and aircraft-based lidar systems have already been used independently for most of the measurement categories.

The acquired information will not only aid global weather forecasting but, more importantly, will help mankind determine and understand the global effects on our environments of an increasingly crowded and industrialized world.

The Space Station will provide the opportunity to pursue long-lasting (five year) lidar missions with in-space resupply of consumables (such as cryogenics and laser dyes), maintenance and repair (especially of lasers) and modification of the lidar system capabilities (mission modification). Mission modification will be possible by replacing one or more of the lidar's laser/detector modules or module pairs.

3.3.4 Resource Observation

Three free flyer Resource Observation Missions are listed in Fig. 3.3-19. Two will operate in low earth orbit and one, the Advanced Earth Resource Serving System I (GRUM 0401), operates in geosynchronous orbit.

The Advanced Land Observing System (GRUM 0400) objectives, from the data source in Fig. 3.3-20, are to advance the capability of land remote sensing instrumentation to provide multispectral data with 15-m resolution in the visible and near-IR and 30-m resolution in the shortwave IR bands, with stereoscopic and cross-track viewing capabilities.

Four spacecrafts are utilized in the GEO system Advanced Earth Resource Sensing System I that satisfy the same objectives of the LEO satellite, Advanced

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	FREE FLYERS				
0400	ADVANCED LAND OBSERVING SYSTEM	89	90	705	EARTH
0401	ADVANCED EARTH RESOURCES SENSING SYS I	97	0	GEO	EARTH
0402	ADVANCED EARTH RESOURCES SENSING SYS II	98	60	400-1630	EARTH

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Fig. 3.3-19 Resource Observation Missions

ID NO.	MISSION/ PAYLOAD	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES					
		UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–	FREE FLYERS						
0400	ADVANCED LAND OBSERVING SYSTEM			R-6			
0401	ADVANCED EARTH RESOURCES SES SYS I			R-12			
0402	ADVANCED EARTH RESOURCES SES SYS II			R-13			

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Fig. 3.3-20 Resource Observation Documentation

Earth Resource Sensing System II (GRUM 0402), which is to provide earth resources and environmental information in the following areas:

- Agriculture
- Range measurement
- Forestry
- Geological resources
- Land use
- Water resources
- Environmental quality
- Disaster assessment
- Weather and climate atmospheric properties
- Earth and ocean dynamics.

The Space Station could support transportation operations of the GEO satellites and servicing of the LEO satellites.

3.3.5 Planetary Missions

Two Space Station attached payloads are listed in Fig. 3.3-21. Both are telescopes; the second listed, Infrared Spectroscopy, is developed from the SIRTF (GRUM 0201), which was first used for astrophysics purpose, then modified for this planetary mission. Figure 3.3-22 lists the data resource that provided the following information.

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	EXTERNAL PAYLOADS				
0275	PLANETARY SPECTROSCOPY TELESCOPE	97	28.5	300	CELESTIAL
0276	INFRARED SPECTROSCOPY (MODIFIED SIRTF)	95	28.5	300	CELESTIAL
	FREE FLYERS				
0325	SATURN ORBITER DUAL PROBE	91	28.5	N/A	N/A
0326	URANUS, NEPTUNE, PLUTO PROGRAM	94	28.5	N/A	N/A
0327	ASTEROID MULTIPLE RENDEZVOUS	96	28.5	N/A	N/A
0328	LUNAR POLAR ORBIT	92	28.5	N/A	N/A
0329	ORBITING IR SUBMILLIMETER TELESCOPE	98	57	700	CELESTIAL

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Fig. 3.3-21 Planetary Missions

ID NO.	MISSION/ PAYLOAD	SCIENCE & APPLICATION PRIMARY DOCUMENTATION RESOURCES					
		UAH/ NASA WORK-SHOP 8/78	PROJECT CONCEPTS 10/80	TECHNOLOGY MODEL 9/81	SPACE OPS CENTER 1/82	PLATFORM PAYLOADS 3/82	S.S. RQMT (DRAFT) 11/82
GRUM–	EXTERNAL PAYLOADS						
0275	PLANETARY SPEC-TROSCOPY TELE-SCOPE						PAGE 73
0276	INFRARED SPECTRO-SCOPY (MODIFIED SIRTF)						PAGE 76
	FREE FLYERS						
0325	SATURN ORBITER DUAL PROBE			P-7			
0326	URANUS, NEPTUNE, PLUTO PROGRAM			P-6			
0327	ASTEROID MULTIPLE RENDEZVOUS			P-5			
0328	LUNAR POLAR ORBIT			P-10			
0329	ORBITING IR SUB-MILLIMETER TELE	P-64	•	S-30			PAGE 12, 78

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Fig. 3.3-22 Planetary Missions Documentation

3.3.5.1 Planetary Spectroscopy Telescope (GRUM 0275) - Many of the principal molecules, atoms and ions in planetary and cometary atmospheres have their important spectroscopic features at wavelengths shortward of 0.3 micrometers. A great deal of physical insight can be gained from spectroscopy in this spectral region, but such observations are impossible from the ground or even from high-flying aircraft or balloons, because strong absorption due to ozone (O_3) makes earth's atmosphere opaque at wavelengths shorter than 0.3 micrometer. Ultraviolet spectroscopy must be done from above earth's atmosphere; it can be done most effectively from an orbital facility since sounding rockets provide only about five minutes of good observation, which is inadequate for many investigations.

Advantages of performing spectroscopic observations from orbit are not limited exclusively to the ultraviolet spectral region. Features due to water vapor (H_2O), molecular oxygen (O_2), and carbon dioxide (CO_2) in earth's atmosphere are superimposed on ground-based spectroscopic observations at visual and infrared wavelengths. Superimposed terrestrial features make quantitative analyses of important planetary spectral features difficult or impossible. Furthermore, turbulence in earth's atmosphere limits the angular resolution of ground-based observations to about 1 arc-sec, which corresponds to spatial resolution of approximately 3000 km on Jupiter. Spatial resolution an order of magnitude better than this is needed for long-term studies of Jupiter's atmospheric dynamics.

3.3.5.2 Infrared Spectroscopy (GRUM 0276) - High-resolution (R 105) infrared spectroscopy from above earth's atmosphere is an extremely important capability for planetary science. This is almost uniquely a planetary science requirement: while certain problems in astrophysics require resolution in the range 103 R 105, the number of scientists engaged in research on these problems is small.

Free flyer pla' ›tary missions are also listed in Fig. 3.3-21. The primary source of information, the NASA Space Systems Technology Model, may be superseded by another approach that emphasizes low costs planetary exploration. The Solar System Exploration Committee could recommend that hardware developed for Voyager, Galileo, ISPM and Pioneer be used for a series of new missions.

3.3.6 Life Science Missions

The primary issue to be resolved is: can humans remain healthy and operate in space for years at a time. Humans experience physiological problems due to zero gravity. Gravity also plays a key role in much of biology. The delivery of health and medical care to the crew, the cabin habitability and the development of life support systems are major factors to be considered in the Space Station. Figure 3.3-23 lists internal payload missions, none constraint orbital parameters.

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM–	INTERNAL PAYLOADS				
0151	CARDIOVASCULAR EXPERIMENTS	92	ANY	ANY	N/A
0152	HEMATOLOGY & IMMUNOLOGY EXP	95	ANY	ANY	N/A
0153	BONE/MUSCLE METABOLISM STUDIES	94	ANY	ANY	N/A
0154	BIOLAB	9r	ANY	ANY	N/A
0155	MEDICAL OPERATIONS	92	ANY	ANY	N/A

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Fig. 3.3-23 Life Science Missions

3.3.6.1 Cardiovascular Experiments (GRUM 0151) - The objective of cardiovascular investigations is to resolve concerns about long-term adaptation or deterioration that is important for prolonged manned missions. Emphasis will be placed on fluid and electrolyte balance and its effects on the cardiovascular system, validation of the use of animal models for study of the human cardiovascular responses to weightlessness, cardiovascular adaptation and possible deconditioning during long-term exposure to weightlessness and changes in cardiovascular regulatory mechanisms and its effect on homeostasis.

No major impairment of cardiovascular function has been observed to date in space flights ranging in duration up to six months. However, functional cardiovascular abnormalities manifested as orthostatic intolerance and reduced exercise capacity have consistently been demonstrated in astronauts during the immediate postflight period. These manifestations, coupled with the fact that exercise capacity is maintained in space, suggest that the postflight cardiovascular dysfunction is the result of an appropriate adaptation to altered fluid distribution in zero g, suddenly rendered inappropriate upon return to the one g environment. Although some factors involved in the adaptation process (blood volume loss, for example) have been identified, the underlying mechanisms are far from clear at the present time. A more pressing problem from an operational standpoint is the development of suitable countermeasures to offset the potentially debilitating effects of cardiovascular deconditioning in zero g. The long-term Space Station studies will provide an opportunity to fully address both these questions.

3.3.6.2 **Hematology & Immunology Experiments (GRUM 0152)** - Clarification of the dynamic events related to the observed decrease in red cell mass occurring during space flight is the basic objective of hematology experiments. Animal and human studies will be designed to improve the understanding of the effect of metabolic balance, erythroid stress and blood volume changes on red cell mass loss during spaceflight and the subsequent postflight recovery period.

A better understanding of immunological function during spaceflight requires animal and human experiments to determine the factors behind significant changes in lymphocyte responses to mitogens, leukocyte function and other significant immunological factors.

The most consistent finding relative to the influence of spaceflight on the hematologic system in man has been a significant reduction in the circulating red cell mass. Different mechanisms have been proposed for this decrease. The most recent data from human experiments support the concept that a suppression of erythropoiesis during flight is the major factor in the change. Some of the factors involved in red cell mass loss will be examined during Shuttle/Spacelab missions. However, the exact etiology of this observed decrease in red cell mass is unknown, and the restrictions such a decrease might place on longer missions remain a matter of conjecture.

During early manned missions there was some evidence of alternations in plasma immunoprotein concentrations and the responsiveness of lymphocytes to mitogens. Skylab and early Shuttle missions also demonstrated postflight decreases in T-lymphocytes and T-lymphocyte function, leukocytosis, and a transient elevation in B-lymphocytes. Very little is known about the kinetics and function of leukocytes during long-term spaceflight. Therefore, to establish the immuno- competence of the crew-members, it is important to evaluate the changes in the immuno system that occur during long-term exposure to spaceflight.

3.3.6.3 Bone/Muscle/Metabolism Studies (GRUM 0153) - Rodent and primate studies will be used to obtain histological data that can be correlated with metabolic balance measurements, bone demineralization measurements, electromyography (EMG), muscle strength and volume. These measurements will be used to assess countermeasures and to assess the degree of musculoskeletal degradation and its impact upon man's long-term performance in space and reentry to earth. Human experiments should confirm the results of animal studies and test the effectiveness of the countermeasures established for long-duration spaceflight.

Using classical balance techniques, calcium loss has been recorded in crewmembers from Gemini, Apollo and Skylab missions, and very significant losses of muscle strength, muscle volume and total body weight have been noted during manned spaceflight. Composite studies of crewmembers from Skylab show calcium balance becoming increasingly negative from -50 mg/day in the second week to -300 mg/day about the 12th week. Skeletal calcium loss has been partially confirmed by photon absorption densitometry that has recorded decreased mineral content of os calsis, distal radius and ulna. Skylab studies of muscle strength and volume show that leg muscle strength decreased nearly 25%, with a 5% decrease in muscle volume and weight during Skylabs 2 and 3, and muscle strength decreased 10% with a 2% decrease in muscle volume and weight during Skylab 4 (with its more vigorous exercise program). A strong indication that the changes in muscle represent a breakdown of muscle tissue comes from the finding that nitrogen excretion exceeded nitrogen intake, and there was a 35% increase in the excretion of 3-methylhistidine, a specific indicator of muscle protein metabolism. Nutrient balance studies are important tools in examining potential problems of weightlessness. In addition to the nutrient balance studies mentioned previously, Skylab studies showed there was also an excess excretion of sodium, potassium and phosphorous during flight. Only

long-duration spaceflights can establish whether muscle and bone atrophy continue indefinitely, or if there is an eventual adaptation.

3.3.6.4 Biolab (GRUM 0154) - The Biolab mission concept provides a facility for the discipline of gravitational biology that includes those areas of life science research that address questions of fundamental biological significance not directly related to the major functional systems included in other disciplines such as cardiovascular systems, hematology, immunology and musculoskeletal metabolism. Among the problems studied in gravitational biology are those that concern gravitropic and phototropic responses of plants, embryogenesis and organogenesis in animals, and animal and plant metabolism and Controlled Ecological Life Support Systems (CELSS).

Previous measurements during space flights have noted that, whereas there seem to be little or no changes in simple cell functions during and following weightlessness, there does appear to be a change in certain tissue and organ constituents in small animals. The origin of such changes is not clear, primarily due to a lack of appropriate controls for the experiments conducted. Exposure to radiation seems to have little effect on the development of lower life forms, but development in vertebrates is affected. In addition, embryological development in the frog has been studied with the experiments showing no effect of weightlessness on the frog's developmental processes. However, all data were collected using embryos which had undergone several cell divisions prior to launch and the studies are not conclusive. At this time, neither ground-based studies (in the centrifuge or clinostat), nor space-flight studies have clarified the role of gravity in embryological development. Long-term spaceflight experiments are needed to study development and reproduction.

Manned space flight has revealed disturbances in the human vestibular system which manifest themselves through space sickness and disorientation. These symptoms occur in approximately 55% of crewmembers and last for three to five days. Two possible causes for these events are a sensory conflict between vestibular, visual and kinesthetic information and/or an inflight change in vestibular physiology.

3.3.6.5 Medical Operations (GRUM 0155) - The objective of the Medical Operations mission is to develop facilities to provide health care maintenance for the crew on long-duration missions. The motivation behind a medical operations program is to maintain the work efficiency of the crews through health maintenance. Work activities will change from the present mix of flight testing, observing and experimenting in the Shuttle program to constructing, repairing and manufacturing. The medical conditions encountered will become more diversified. Typical medical problems which may arise are in the following categories:

- Standard medical-surgical conditions of adults, e.g., infection, heart attack, kidney stones, accidents (fractures, bruises,) etc
- Those conditions unique to space, e.g., space sickness, radiation and postflight conditions resulting from spaceflight (joint injuries, micro- fractures and postural hypotensions)
- Psychological problems related to the isolated environment.

3.3.7 Materials Science Missions

The objective of performing materials research in the space environment is twofold: (1) investigation of fundamental properties and processes that may impact ground based activities; and (2) identification of unique responses and capabilities that might be explored in space. Materials science aims at numerous areas of interest with specific commercial applications, with the expectation that some of the knowledge gained will lead to practical applications. Four areas of investigation are listed in Fig. 3.3-24 and discussed in the following subsections.

ID NO.	PAYLOAD/MISSION	IOC	INCLIN (DEG)	ALT (km)	POINTING DIRECTION
GRUM-	INTERNAL PAYLOADS				
0175	VACUUM VAPOR DEPOSITION STUDIES	93	ANY	ANY	N/A
0176	CHEMICAL REACTION STUDIES	91	ANY	ANY	N/A
0177	UNDERCOOLED SOLIDIFICATION STUDIES	91	ANY	ANY	N/A
0178	THERMOPHYSICAL MEASUREMENTS	91	ANY	ANY	N/A

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Fig. 3.3-24 Material Sciences Missions

3.3.7.1 Vacuum Vapor Deposition Studies (GRUM 0175) - The objective of the mission is to explore new technology for deposition of thin semiconducting films in ultra-high vacuum using the extremely high vacuum pumping rates in a wake shield facility. NASA-funded efforts have already shown that, in the best vacuum maintainable during vapor deposition in terrestrial experiments, crystalline semiconductor deposits can be laid down at much lower temperatures than when using chemical vapor techniques. This possibility, in itself, opens up new prospects for sequential processing of integrated circuits and other devices where presently the high (1000°C) required deposition temperatures destroy by diffusion any structures laid down previously. Other studies have shown that, in a wake shield facility, vacuum levels at least three orders of magnitude better than 10^{-10} during deposition could be achieved. On theoretical grounds, it is highly likely that such improvement over terrestrial techniques could lead to beneficial improvement in purity and freedom from defects for such semiconductor layers and devices.

The requirements of a vacuum wake shield evaporation/deposition facility may well exceed the projected capability of the STS sortie mode. This follows from the rather large investment in time and energy to outgas the shield, the outgassing power requirements, the necessity for frequent hands-on changes in source and substrate arrangement, plus the possible requirement for EVA occasional cleaning and decontamination of the shield, particularly when changing source material. As an alternate to cleaning the shield, installation of a new thin liner previously stored in a clean container can be considered. In any event, the wake shield must be located at a considerable distance (more than several hundred meters) from any manned vehicle in order to avoid contamination. This in itself calls for a co-orbiting free flyer probably more adapted to a Space Station than to a Shuttle Sortie mission.

3.3.7.2 Chemical Reaction Studies (GRUM 0176) - Mission objectives are the measurement of reaction rates and formation of ultra-pure compounds by containless techniques. The work will emphasize formation of compounds of highly reactive and refractory materials, including single crystals.

Space Station implementation of the containless chemical reaction facility would greatly increase the cost effectiveness of an extensive series of reaction experiments on a wide variety of chemical compounds and semiconductors, as compared to a short-lived sortie mission implementation.

The initiation of this mission should lead to significant new developments in understanding of chemical thermodynamics of high temperature, reactive systems where progress at present is hindered by lack of suitable crucible techniques. There is a possibility that technical advances could result from the preparation and study of ultra-pure semiconductor and other compounds where electrical or optical properties are determined primarily by impurities.

Although such a mission can be considered in the STS sortie mode, in-orbit availability would be rather short to amortize the large launch investment. It is also expected that for maximum cost effectiveness, considerable astronaut/technician participation in flight will be necessary to develop in-flight techniques to maximum effectiveness by allowing rapid changes in experiment procedures and specimen selection.

3.3.7.3 Undercooled Solidification Studies (GRUM 0177) - Objectives of the mission are the study of nucleation in undercooled melts, investigation of new metastable phases produced by undercooled solidification and production of bulk metallic glasses. Rapid cooling can also lead in some instances to single crystals of difficult-to-produce refractory materials.

Work attempting to achieve fundamental understanding of the solidification process by undercooling studies has been underway for many years in a number of laboratories. Elimination of heterogeneous nucleation provided by container walls has been a natural tool in such investigations. Containerless undercooling utilizing electromagnetically levitated melts has achieved limited success and it is natural to consider extensions of the technique possible in a microgravity environment.

Useful Space Station attributes for implementing this mission are the hands-on interaction possibilities for rapid modification of experiment procedures based on early results obtained and the possibility for providing more elaborate provisions for ultra-high-vacuum pumping, in situ specimen surface cleaning and observation and more complete instrumentation. The facility would be located internal to the Station, as near as possible to the center-of-mass. A crew of two astronaut technicians for seven hours a day would be desirable. Operation by a single astronaut is possible provided another technician for equipment maintenance/repair is available part time.

3.3.7.4 Thermophysical Measurements (GRUM 0178) - The mission objective is to determine high temperature values of specific heat, viscosity, thermal conductivity and vapor pressure for a number of materials of scientific and technical importance. This originates from the need to extend the work currently being carried out in ground-based laboratories to include high melting, poorly conducting or high density materials for which no ground-based techniques exist for the measurements. Space-based techniques will allow the containerless melting, observation and subsequent manipulation of such materials for which in-crucible techniques do not exist. Development of such techniques is presently being funded under the NASA MPS program.

This mission exploits the availability for man-equipment interactions in a shirt sleeve environment offering microgravity. It is assumed that peak powers of the order of 50 kW will also be available for periods of a few minutes at a time. Isolation of the facility during experiments at the highest powers and pressures, or to achieve lower g- levels will also be an attractive Space Laboratory option in later phases of the program. A crew of two working for eight hours per day can initiate such a program in the first year. Later the second crewman could be dispensed with except during repair periods.

3.4 TECHNOLOGY DEVELOPMENT

This topic addresses the technology development activities that can be performed on an evolutionary long-life Space Station. Commercial mission R&D activities that benefit private enterprise are included in the Baseline Mission Model. The two missions in this category are discussed in Subsection 3.2, Communications R&D Lab (GRUM 1000) and Materials Processing Lab (GRUM 1100). Other representative technology missions are discussed in the following paragraphs.

3.4.1 Controlled Ecological Life Support Systems (CELSS)

The eventual goal of this set of experiments is the development of an Environmental Control and Life Support system that can support crews indefinitely without the need for resupply. Since the ECLS configured for the Evolved Space Station incorporates both oxygen regeneration and water reclamation systems, the major unresolved area for the development of a CELSS is the recycling of metabolic wastes and refuse to produce food. The food regeneration systems to be developed will involve both biological and non-biological processes which must be functional in the Space Station environment. Of particular concern is the adaptability of biological

processes to zero gravity. Therefore, the need to perform these experiments on the Space Station. Experiments will include the evaluation of various biological wastes disposal systems (biodigesters) and various processes food growing food including geniponics, aeroponics, etc.

3.4.2 Large Structures Technology Development

Before building a particular operational or R&D structural platform in space, it is advisable to develop a technology base for such structures as well as the equipments necessary for their assembly and handling. The Space Station would support that activity.

Key issues associated with this technology development are: support equipment interfaces; man, man-machine, and machine functions; crew skill requirements and space station operational interface requirements. Robotic constructions may also be considered in developing this technology.

The experiment structural elements will be transported to orbit in the shuttle. They will be assembled and rigged to provide the appropriate structure; then a topographical survey performed. Static and dynamic tests will be performed to determine critical frequencies, mode shapes, damping characteristics and dispersed control effects. Thermal distortions due to in/out of sunlight will be measured.

Following the tests, the structure will be inspected and any faults repaired. It will then be refolded or disassembled and stowed on the Space Station for subsequent tests.

3.4.3 Large Antenna Technology Development

This experiment would establish a technology base for the construction and calibration of large phased array and reflector antennas.

Key issues are: the deployment of the folded planar antenna; maintenance of surface figure and orientation; measurement of beam patterns and side lobes.

The experimental antenna will be transported to orbit and folded in the shuttle cargo bay. It will then be deployed and tensioned, and a topographical survey performed. It will be instrumented to measure dynamic response to environmental

inputs, control system commands, and surface and structural distortions due to dynamic inputs and thermal effects. Beam patterns and side lobes will be measured using a co-orbiting RF source.

Following the tests, the antenna will be inspected and any faults repaired. It will then be refolded and stowed on the space station for subsequent tests.

3.4.4 Large Optics Technology Development

This experiment would establish a technology base for the construction and operation of large aperture segmented mirrors, having high optical surface accuracy. Key issues are maintenance of surface figure and segment orientation through positional actuators and control algorithms; measurement of optical image quality through wavefront sensing techniques; deployment, erection, and mechanical vibration control of the truss support structure for the primary mirror.

The experiment reflector elements will be transported to orbit in the shuttle. They will be assembled and rigged, then a figure survey performed. Static and dynamic tests will be performed to determine critical frequencies, mode shapes, damping characteristics and dispersed control effects of the primary mirror support structure. Optical performance of the assembled reflector will be confirmed by astronomical observations. Thermal distortions due to in/out of sunlight will be measured.

Following the tests, the reflector will be inspected, disassembled and stowed on the Space Station for subsequent test.

3.4.5 Air Maneuvering OTV Technology

The thermal protection, aerodynamic control and guidance algorithms for an air maneuvering reusable orbital transfer vehicle can be evaluated by testing an article deployed from an OTV. An OTV, when deploying other payloads to GEO, can carry the test article as a parasite payload. The article is separated on the return leg and placed in an atmospheric perigee orbit by its own propulsion system. Data must be recorded onboard and dumped later. Recovery of the article is also a desirable possibility. The Space Station is not essential for these tests, but is convenient because it is the base for OTV operations.

3.4.6 High Specific Impulse Propulsion

The Space Station can provide the presence of man to set up, initiate and monitor tests of high specific impulse propulsion systems in the unlimited vacuum of space. Systems may be modified and retested if the propellant is replaced.

Opposing pairs of rocket nozzles are used to minimize disturbances to the Space Station.

3.4.7 Low Loss Cryo Propellant Storage

Presently, loss of propellants due to boil-off is a problem when storing cryo propellants for a long time. The Space Station is a convenient location for micro-g testing of possible new storage systems which reliquify boiled-off propellants. These tests would be continuous over long durations (30-90 days) and would benefit from man's occasional interaction.

3.4.8 Liquid Droplet Radiator

The candidate liquid droplet radiator systems could be intergrated/connected to the Space Station Thermal Management System at the heat rejection interface point. The system assembly would be installed as an auxilliary experimental heat rejection system. Waste heat load would be supplied by the space station (as an option a separate heat source could be used) commensurate to the size of the liquid droplet radiator system. It would operate at actual space station radiator conditions of inlet and outlet temperature, zero gravity, vacuum, solar radiation, attitude correction and maneuvering perturbations and with the interface of space plasma. Performance would be evaluated for efficiency of waste heat rejection, response, temperature distribution controllability, flow rate, potential of loss of working fluid and space station contamination due to vaporization and manuevering and effect of space plasma interface on liquid droplet streams trajectory. Zero-gravity effects on droplet generation, trajectory and collection efficiency would be determined. Constraint on operation control and performance will be determined. Performance, failure modes, and lifetime potential will be evaluated using operational data to correlate space and ground test data. The mission would require evaluation under startup, shutdown, full and part load operation.

The liquid droplet system has numerous advantages. The system is less that 1/4 of the weight of flat plate, tube-fin and heat pipe radiator designs. Radiator concept does not require surface coatings or armor-plate protection. Radiating area

is impervious to micro meteroid damage. Liquid droplet radiator is suitable for low temperature (300K) and high temperature (1000K) NASA and DoD applications in kilowatt and megawatt range. The system is deployable, offers compact stowed configuration, and can be designed to survive launch environment.

3.4.9 Earth Observation Instrument Development

One of the major problems in developing earth observation scientific and operational instrumentation (especially when the physical process to be sensed is only partially understood) is the need for specialized facilities which duplicate the expected environment. For the class of instruments discussed here, the environment of interest is usually related to atmospheric absorption in the new region of interest, effects of various viewing or illumination angles, seasonal variation, and effects of various degrees of cloud cover or moisture content. The space station provides an ideal facility for rapid assessment of these and as yet undetermined factors without continuing major investments in new developmental facilities. The Space Station is an all-encompassing facility with exact modeling of all known and unanticipated phenomena of interest for earth-oriented sensors. It is often the case that the solution of very difficult problems become intuitively clear when all the proper constraints are brought together in such a facility.

Instrument development requires continuous, or at least long-term (hours) earth orientation, usually nominal power, but could be considerable. Some experiments will require sensor cooling ranging variously from nominal through cryogenic.

3.4.10 Advanced Automation Technology Development

Advanced automation systems have been identified as a critical aspect of the Space Station system both in its initial implementation and in successive evolutions of the system. This mission is the required follow-on effort to refine, extend and develop additional advanced automation system capabilities that require the use of the Space Station as a test bed. The Space Station provides the required interactive environment to further define real system needs, detail more suitable procedures, implement revisions and maintain the system in an operational mode. This mission will provide the technology needed for expansion of the advanced automation system capabilities that are essential for evolutionary Space Station management and growth. Crew/Ground Support activities required for Space Station Systems "Housekeeping" and operational activities will develop well defined procedures as

experience in the space working environment increases. These procedures will range from the trivial to the exceedingly complex, as well as from entertaining to tedious. All procedures must be analyzed to determine what the optimal man/machine interface should be. Procedures that can be made more effective by using advanced automation systems can increase the efficiency of the Space Station system. All "housekeeping" and operational activities will be monitored/recorded for detailed review. Crew comments and suggestions will be solicited both preceding, during and after activities. Crew members will be provided continual access to a high level (natural language if possible), real-time interactive link to the advanced automation systems. This link will enable both direct control (subject to safety buffer/review where required) of connected systems and provide action simulation capabilities Also, the links will allow access to all available Space Station-related information via a fully integrated information management system.

This mission will allow the crew/ground support time required for "housekeeping" and routine operational activities to be minimized. The mission will provide for the optimal use of the crew in the man/machine interface, thereby improving Space Station operational capabilities. Advanced automation systems will help make Space Station systems affordable, as well as facilitate their expansion.

3.5 FOREIGN MISSIONS

The two major geographical areas that will be involved in Space Station activities are the European countries and Japan. Europeans, through ESA, are conducting studies that will yield recommendations for their participation. The Japanese are also making good progress advancing their involvement in space, and could make a significant contribution to Space Station. Canada has an interest in being the supplier and user of future space services including Space Station.

3.5.1 Space Station Support of European Missions

Grumman has met with the British Aerospace Corp, Dormier GmbH, and ERNO personnel to learn about their space plans. The subsequent paragraphs are based on these discussions, published reports and presentations to NASA.

European missions that require or could benefit from Space Station support are similar to the U.S. identified missions. In the early 90s, Space Station can support the servicing of free flyers, and serve as a base for internal and external pay-

loads. Further, it can support technology development of instruments, investigation of space procedures and techniques, assembly of upper stages to payloads and construction of space platforms. A schedule of selected European satellite missions is shown in Fig. 3.5-1 for the 1990s when Space Station will be operational.

MISSION	CALENDAR YEAR '90	'91	'92	'93	'94	'95	'96	'97	'98	'99
EURECA II	–	Δ	–	Δ	–	Δ	–	Δ		
EUROS/SOLARIS		Δ JLG & SVCG		Δ RENDEZ & DOCK			Δ TELEOP			Δ FULL SYS OP
METEOROLOGY FOLLOW-ON	Δ	–	–	–	–	–				
EARTH OBSERVATION FOLLOW-ON			Δ	–	O	–	O	–	O	–
EARTH REMOTE SENSING (ERS-3)		Δ	–	O	–	O	–	O	–	
GEO PLATFORMS									Δ	–

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Fig. 3.5-1 Schedule of Selected European Missions

The experience gained by Europe in the Spacelab development program, and the specific needs of the users for extended mission duration under microgravity conditions, have led Europe to follow an approach responsive to its own needs and compatible with its financial resources. From studies which have been carried out by the European Space Agency (ESA), the conclusion has been drawn that the development of a free flying re-usable carrier should be pursued. The basic objective of the "EUropean REtrievable CArrier" (EURECA) (Fig. 3.5-2) is a payload carrier, initially dedicated to microgravity, which will be deployed from the Shuttle cargo bay, in 1987, will operate in a free flying mode for approximately six months, and will then be retrieved together with its payloads, returned to earth by the Space Shuttle, and prepared for further missions. EURECA is regarded as the first step in an evolutionary program that may finally lead to an unmanned or man-tended European space platform, depending either on being serviced by the Shuttle, or operating completely automated. This platform would be devoted to microgravity research, earth observation, astronomy or other investigations.

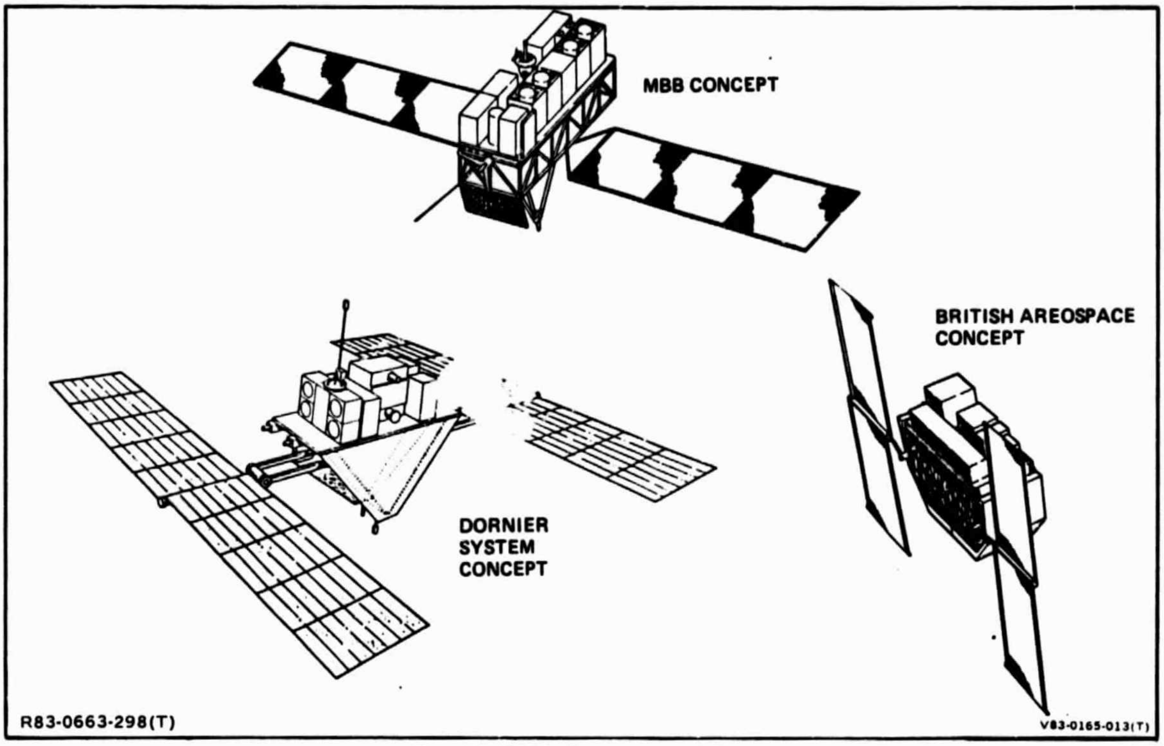

Fig. 3.5-2 Configurations of Eureca

In anticipation of a growing need for more material samples and larger sample sizes for on-o bit assembly and construction/activities etc, one may envisage platforms of larger dimensions than the retrievable carrier and with an on-orbit operational life time of 10 and more years. Therefore, the "EUropean Retrievable Orbiting System" (EUROS) (Fig. 3.5-3) has been conceived by the Germans.

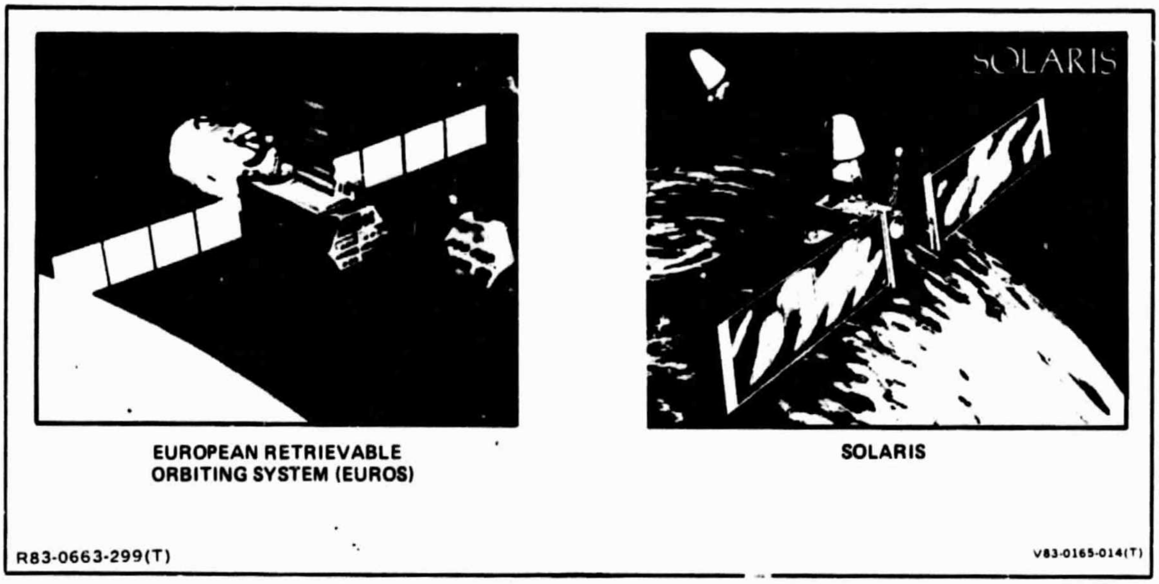

Fig. 3.5-3 Large European Platform Approaches

Whereas the EURECA is a single element (i.e., one pallet or segment), EUROS consists of:

- An orbit-based Service Module (SM) to provide all resources and on-board capabilities for a fully autonomous station
- A Payload Processing Module (PM) to carry the payload processing facilities, docked to the SM
- A Logistics Module (LM) to resupply the consumables of the SM, to provide reboost capability and to supply the equipment needed for in-orbit repair and maintenance of the SM.

Another approach to meeting large platform requirements is the French Solaris configuration (Fig. 3.5-3). It is designed to be launched by Ariane in an 800-km altitude, sun-synchronous circular orbit, serviced remotely, and payloads returned to earth in a transportation module.

All elements of EUROS are intended to be launched by the Shuttle or Ariane, and they should be accessible and retrievable by the Shuttle for repair and maintenance.

Besides fulfilling future European needs in the field of microgravity, earth observation and possibly communication, EUROS/Solaris will also serve as a basis for technology demonstration in the areas of rendezvous and docking, remote-controlled handling, servicing and maintenance, re-entry and recovery, possibly on-orbit assembly and construction and space basing of orbit transfer stages. In a long-term prospect, EUROS could be seen as an orbital station that will also support manned modules.

Shuttle/Space Station could support the development of EUROS/Solaris, as shown by the milestones in Fig. 3.5-1, leading to the fully operational system in 1999. Orbital handling and servicing, rendezvous and docking and tele-operator system technology and development all could be enhanced by use of the Space Station. Servicing of the Earth Observation Platform follow-on and EUROS, Fig. 3.5-4, is indicated in Fig. 3.5-1 being performed every two years, possibly by Space Station.

The Space Station could be the assembly location for the Meteorology Satellite follow-on, and the Communications and Astronomy GEO Platforms (Fig. 3.5-5) for attachment of upper stages that transport these satellites to geosynchronous orbit.

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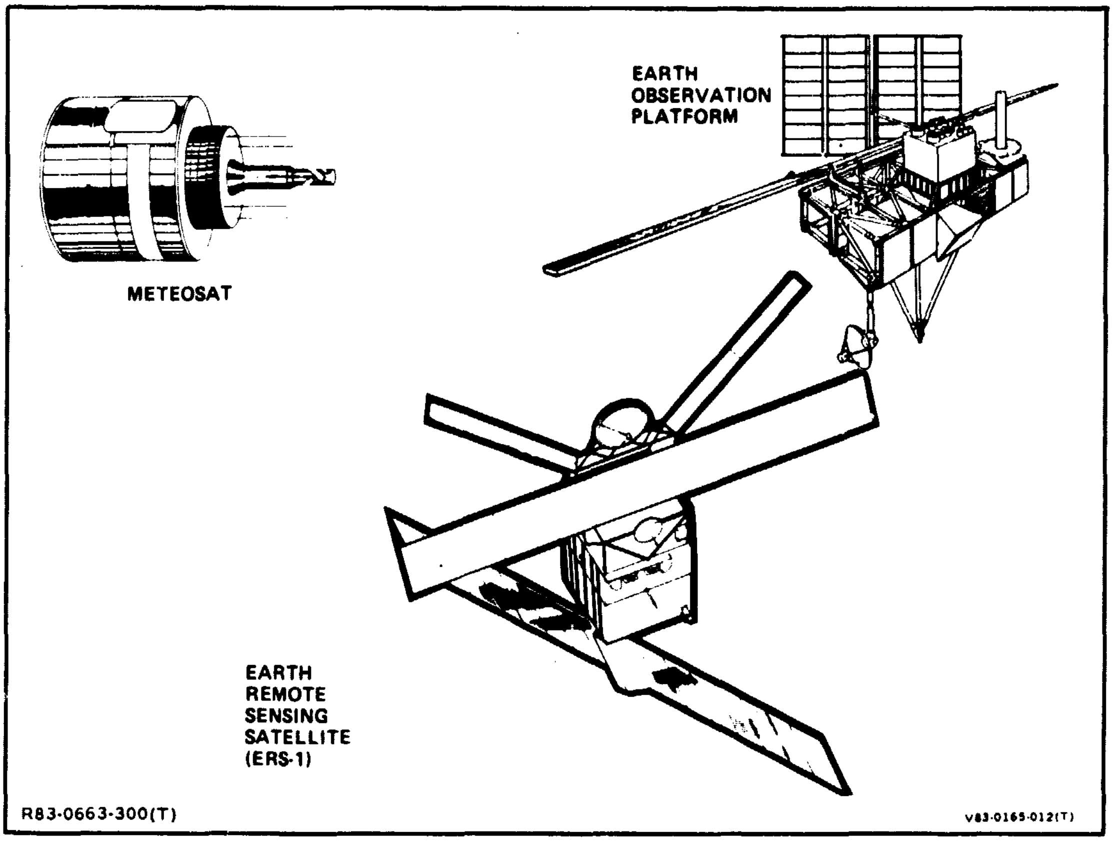

Fig. 3.5-4 Low Earth Observation Platform Concepts

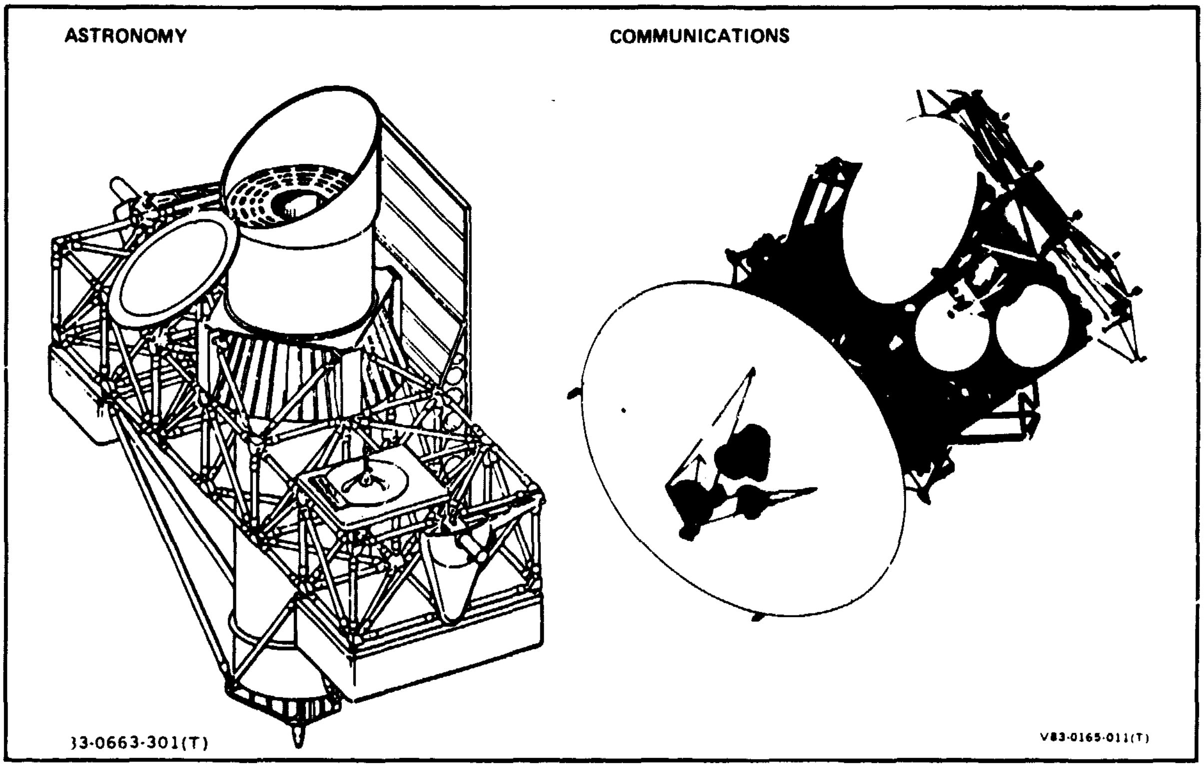

Fig. 3.5-5 Geostationary Platform Concepts

ESA considered the following user disciplines in establishing requirements for internal and external payloads:

- Material science and processing
- Lite science
- Earth observation
- Space science
- Telecommunications
- Space technology
- Operations.

3.5.2 Space Station Support of Japanese Missions

Information from Aerospace Daily, Flight International and Japanese presentations to NASA are the sources of the following subsections. Japan's space activity grew sharply during the early 1970s, but since 1975 spending has been roughly constant, when inflation is discounted. Japan now has launchers capable of placing small craft in geostationary orbit, as well as the expertise to build sophisticated satellites. This position still lags behind Europe and the U.S., but not by much. Japan is well placed to enter the commercial marketplace in the next few years, and could capture a significant slice of the growing demand for satellites.

A recent proposal sent to relevant government agencies (including the Science and Technology Agency, three Mitsubishi companies - the Mitsubishi Corp. trading house, Mitsubishi Heavy Industries and Mitsubishi Electric Corp.) urged that Japan budget $2.2 billion to develop and build major subsystems for the American Space Station.

Mitsubishi explained that Japan's participation in the project would help defuse the trade dispute with the U.S. and promote the growth of the country's fledgling space industry.

The industrial group earmarked three Space Station systems that Japan could work on. They include manned modules that would be connected to the Space Station, unmanned platforms that would fly alongside the main Space Station and "space cabs" that would ply between the Space Station and the free floating platforms.

The National Aerospace Laboratory is currently conducting the following Space Station relevent studies:

- Space Agriculture and Ecological Life Support System
- Microgravity Relevant Materials Science and Technology of Japan
- Multipurpose Solar Collector
- Real Time Reporting System on Ocean Conditions
- Vibration-Free Bench for Microgravity Experiments
- Space Test Facility for Electric Propulsion
- Linear Acceleration as a New Orbit Transfer Vehicle (OTV).

The institute of Space and Astronautical Science has proposed the following Space Station missions:

- Infrared Interferometer in Space
- Infrared Observatory in Space
- X-Ray Observatory
- Composition and Nuclear Interaction of Heavy Primaries in Cosmic-Rays
- Isotope Separation of High Energy Heavy Primaries
- Line Gamma-Rays
- Gamma-Ray Burst Detection
- Gravity Wave Detection In Space
- Tether Experiment
- Advanced SEPAC
- Objectives of METRAS/MINIX
- Collision Protection Radar Experiment
- Typical Radar Performance
- Space Agriculture Experiment
- Molecular Beam Graphoepitaxy
- Trial Process of Amorphous Si Cell for SPS
- MPD Solar Electric Propulsion Test
- Deployable Solar Array Module.

The recommendations of these studies and others, and resulting experimental hardware, will be available for development and use on the Space Station.

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4 - INTEGRATED MISSION RELATED REQUIREMENTS

Analysis of the Space Station related mission orbital requirements, and cost/budget assessment of the aggregate of missions, led to the baseline mission model discussed in Section 2.

Orbital elements required to support the baseline mission model evolved from the mission needs and transportation related requirements. Also, Shuttle performance and launch constraints provided boundaries for selection of orbital element operational parameters. The nominal Shuttle orbit of 28.5 deg is most cost effective for payload to orbit; therefore, missions that have compatible orbital parameters were assigned to a Space Station in this low inclination orbit. Next, missions that require higher inclination were examined and categorized into 57 deg inclination and polar orbit. Shuttle flights/year required for civil activities at these three inclinations were presented at the Mid-Term Briefing. It showed low potential for traffic to higher inclination orbits. Subsequent analysis confirmed this trend. Although shuttle transportation costs to 57 deg inclination orbit are one-half of the transportation costs to polar orbit, there were not enough missions that could function in a 57 deg orbit to justify a permanent presence at that inclination. All of these missions have been integrated with the polar orbit missions where, in fact, they perform quite satisfactorily.

Figure 4-1 shows the Shuttle flight to support a 28.5 deg inclination Space

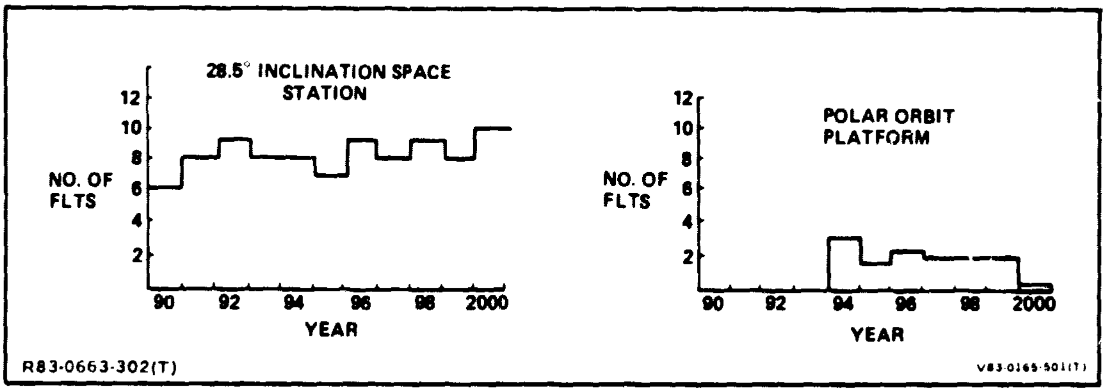

Fig. 4-1 Number of Shuttle Flights Baseline Mission Model

Station. This averages about eight flights/year during the decade of the 90s, and includes support for all missions to geosynchronous orbit (civil and military). The figure also shows Shuttle flights to the polar orbit platform commencing in 1994. Three flights are necessary during the first year to support Station assembly operations; subsequent flights average two/year for payload and platform support.

A study was performed to determine if the wide range of science and application payloads, many of which have been initially defined as free flying satellites or as Shuttle/Spacelab compatible experiments, could be integrated/attached to the Space Station either internally or as an external mount. About 85% of the experiments studied were compatible for integration with the Space Station. As a result, most of the science and application mission/payloads are flown attached to the Space Station. These include astrophysics, life science and material science missions.

4.1 28.5 DEG SPACE STATION ARCHITECTURAL REQUIREMENTS

The 28.5 deg Space Station requires implementation of a full range of Space Station functions to meet the needs of the Baseline Mission Model. These include:

- Space facility/range
- Transportation harbor
- Satellite servicing/assembly
- Observatory
- Industrial park.

4.1.1 Space Test Facility/Range

The first application of the Space Station is to provide a Space Test facility (Fig. 4-2). The need for a space test facility has existed since space exploration commenced. Our approach prior to the Shuttle era was to perform development testing using either large vacuum chambers on the grounds, or to launch systems that have been sufficiently proved out so we had high confidence of their success. This constraint is one of the reasons that space assets cost so much to develop. We have yet to attain the space equivalent of the wind tunnel for aircraft development. Now, with the Space Station, it should be possible to provide such a capability with manned interaction in the experimental development process. The space test facility could then include an attached laboratory as has been done in previous Space Stations (the U.S. Skylab and Russia's Salyut); but with the limitless space available to us, it also is possible to provide a large test range (as

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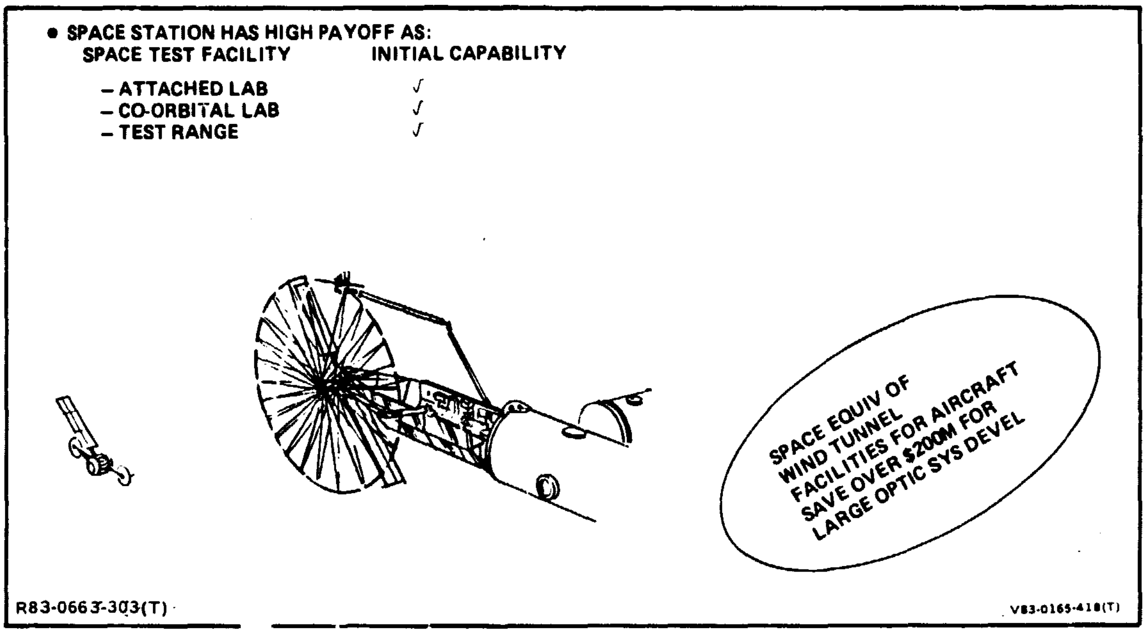

Fig. 4-2 Space Test Facility

shown in Fig. 4-2) where the large and small antennas of the future can be tested with signal generators and diagnostic satellites strategically placed "down range" of the Space Station so that far-field experimental results can be obtained. This testing is discussed in Subsection 3.2.1, Land Mobile Communication Satellite System. Now, with man in orbit and interacting with the test facility (as we do with the wind tunnel), we may change configuration and other test variables to develop the system and prove it, in orbit. Thus, we could reduce the development cost of future space systems. In one illustrative case concerning the development of a large optic system, analysis of the development timeline shows that over $200M could potentially be cut from that program with the presence of Space Station performing the function of a national spac[illegible]t facility.

Most new instruments for earth observation could benefit from space operation during their development to optimize performance and operational techniques. Indeed, the validity of new concepts could be ascertained prior to committing to full scale instrument development.

A positive step toward the establishment of broad industrial participation in the Space Station was suggested by members of GE's Space Station Corporate Advisory Board. The concept is to provide an Industrial Research Facility on-board the Space Station to permit commercial and research organizations to conduct materials research and development relevant to potential commercial products or services. It

is envisioned that portions of this research will ultimately lead to commercial production in space, while other investigations will lead to knowledge that will enable or facilitate improved manufacturing processes on earth. This type of facility will make it possible for industrial concerns such as GE to conduct proprietary or open investigations in support of their current and projected product line. This will include the determination of processing parameters that would enable them to make accurate economic assessments leading to decisions on commercialization. This concept is discussed in detail in Vol II, Book 2, Part II.

4.1.2 Transportation Harbor Requirements

The word transportation "harbor" conjures up the concept of a place where ships find refuge from storms at sea, load/unload their cargo and transfer the cargo to other means of conveyance. So it is with Space Station in its transportation harbor function (Fig. 4-3). The first application of Space Station might be in the

	INITIAL CAPABILITY
• TRANSPORATION "HARBOR"	
– SHUTTLE SUPPORT (EMERGENCY REPAIR, SHELTER)	√
– UPPER STAGE OPERATIONS	
PROXIMITY OPERATIONS VEHICLE REFUEL	√
TMS REFUEL	√
STORABLE OTV REFUEL	
CRYO OTV REFUEL	
ION REFURB	
STAGE/PAYLOAD ASSY	√
– STORAGE FOR "ON-DEMAND" CAPABILITY	√

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Fig. 4-3 Transportation Harbor

category of Shuttle support for, as we get routine and frequent Shuttle flights, reality must admit to the possibility of an orbiter malfunctioning. Being able to dock the Shuttle on orbit at the Space Station where such emergency measures as thermal shielding repair/replacement and shelter for the crew in case of more significant difficulties with the orbiter, is a key capability for reducing the long term risk of

serious accident. The next application of Space Station as a transportation harbor is in the field of upper stage operations; here, in its earliest concepts, small "proximity operations" vehicles will be used to fly from the Space Station to satellites and inspect them. Following inspection they could either be towed back to the Space Station or, if necessary, be repaired remotely from the Space Station but controlled by the crewman within the Space Station through closed circuit TV. From this first start in upper stage operations, future storable propellant upper stage vehicles such as the Teleoperator Maneuverable Systems (TMS) could be refuelled on-orbit thus avoiding the added cost of transporting the TMS to the ground and back again for subsequent operations. Beyond that, we have options for refuelling cryogenic orbit transfer vehicles that are likely to be in service during the 1990s. Eventually, we can expect future satellites to be large enough that they cannot be launched in one Shuttle flight; we then have the need for on-orbit payload assembly to the upper stage. One of the most attractive features of using the Space Station as a transportation harbor is its use for storing our upper stage vehicles as well as payloads to provide "on-demand" capability. That is, we have now removed our dependence upon good weather for launch and can provide the space asset at its operational orbit, launching it from earth orbit.

Transportation to geosynchronous orbit (GEO) could also benefit from a 28.5 deg Space Station. Here the major issue is whether a transport harbor in concert with a reusable orbital transfer vehicle (OTV) is competitive costwise with expendable stages for transport to GEO. A trade-off study was performed to resolve this issue.

4.1.2.1 Benefits Analysis for 28½ Deg Transport Harbor - Previous studies for NASA on MOTV have shown significant savings in GEO transport costs by space-basing an OTV. These savings derive from:

- Not having to relaunch the OTV core each time a mission is required
- Greater performance of a space-based OTV over its ground-based counterpart
- Better manifesting of the Shuttle.

Naturally, any payback is highly traffic-dependent, but as will be seen from the enclosed analysis, for quite modest traffic rates both the space-based OTV and its transport harbor can be paid back in a little as four years. A two and one-half to five-year payback is considered a good business investment.

The civil and DoD traffic to GEO in terms of numbers of payloads and weight of payloads was derived for the 1990s (Fig. 4-4). To satisfy this requirement, three types of ground-based OTVs and two types of space-based OTVs (Fig. 4-5)

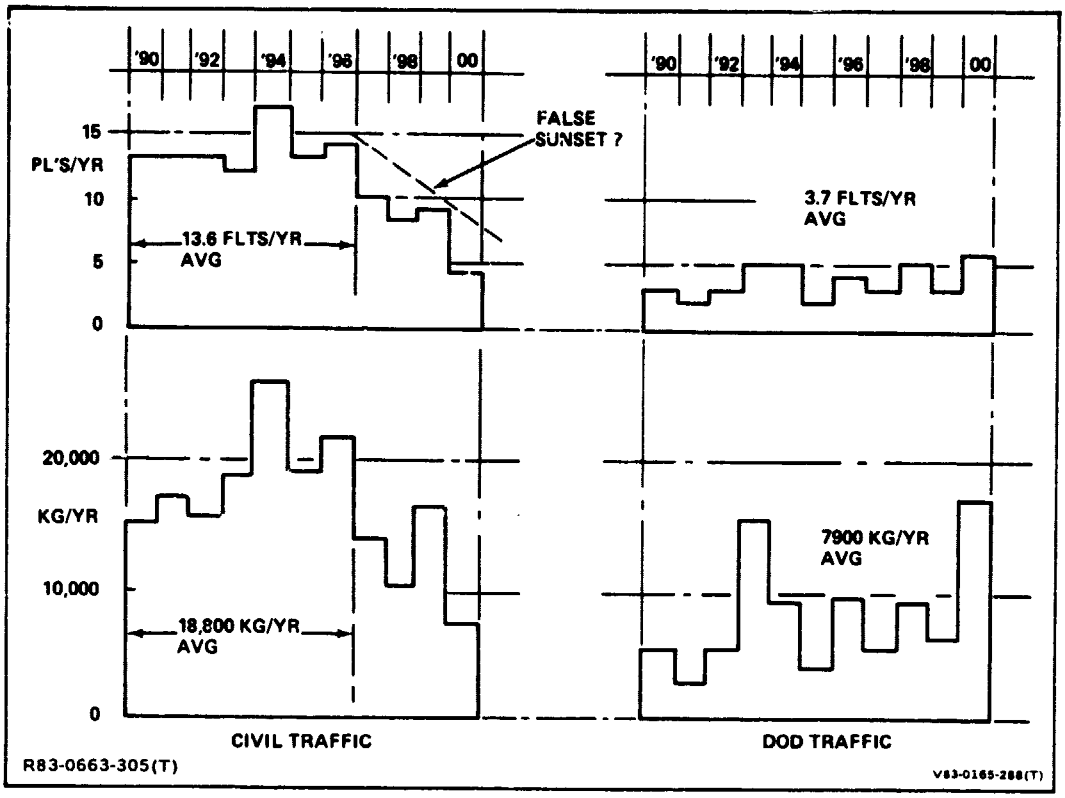

Fig. 4-4 Satellite Traffic to Geo Thru 28.5°

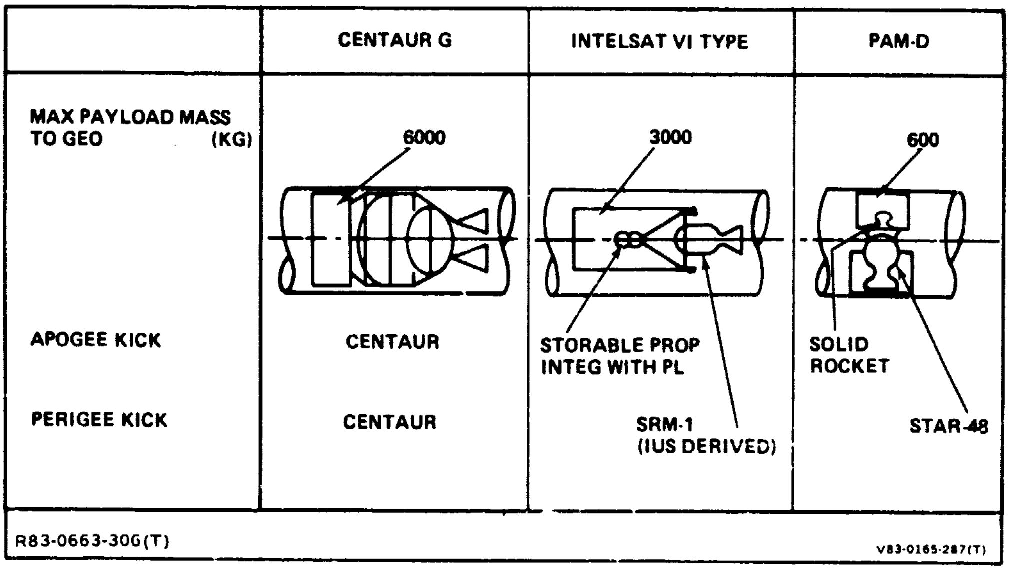

Fig. 4-5 Three Expandable Shuttle Based Methods for a PL Transfer to GEO

were studied. A comparison of their performance in $/kg is presented in Fig. 4-6 assuming a Shuttle load factor of 100%. In a separate study not included here, Shuttle manifesting using each of these stages showed marked differences in Shuttle manifesting efficiency for each upper stage; Fig. 4-7 shows the results of that study. Clearly a space-based reusable upper stage is the most cost-effective form of transportation provided the payload mass to GEO is greater than 4000 kg per OTV flight. Typically, combined payloads run in the range from 3500 to 9000 kg. Thus, by combining payloads on one OTV flight, an efficiency in scale is obtained in addition to the above mentioned STS manifesting benefits. Figure 4-8 compares the recurring cost for GEO transport using the most cost-efficient ground-based mode vs the space-based mode over a typical four-year interval. If both military and civil traffic is considered, a $318M/year savings can be obtained by space basing. However, against this savings the cost of developing both the OTV and its transport harbor must be amortized. Figure 4-9 shows the "add-on" transport harbor recommended for the evolved Space Station for military and civilian usage. Note the deployed security shield to separate civilian and military space operations. A stand alone harbor was also considered (not shown), and both are costed in Fig. 4-10 which shows payback period for each of two transport harbor concepts. Payback in four to seven and one-half years is possible with currently projected traffic rates (approximately eight OTV flights to GEO per year); this would be cut by 50% with twice the projected rate. At approximately three-times the traffic rate, the transport harbor must be enlarged to handle the increased traffic. This case has not been analyzed. Figure 4-11 summarizes other benefits of space-based OTV including these mentioned above.

This study indicated that a reusable OTV is in fact a cost-effective mode of operation and the transport harbor forms an integral part of the evolutionary 28.5 deg Space Station.

4.1.3 Satellite Servicing & Assembly

The next major area for high payoff with Space Station is that of satellite servicing and assembly. Incorporating a transport harbor and externally mounted payloads as Space Station elements strongly influences the role of the Space Station for assembly and servicing. Assembly/integration and manifesting of payloads in close proximity to the Space Station represents a significant activity. Servicings and refurbishments of Space Station attached payloads can be accomplished in a

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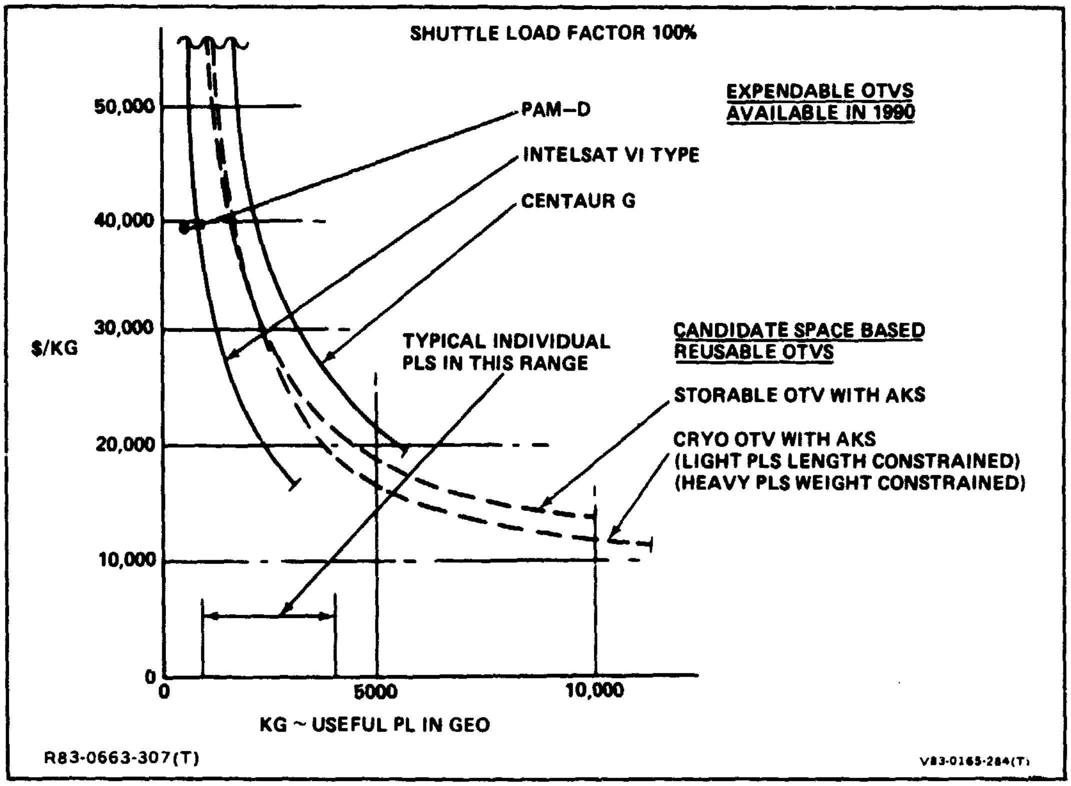

Fig. 4-6 Cost ($'84) of Ground to GEO Transport as a Function of Useful Mass in GEO

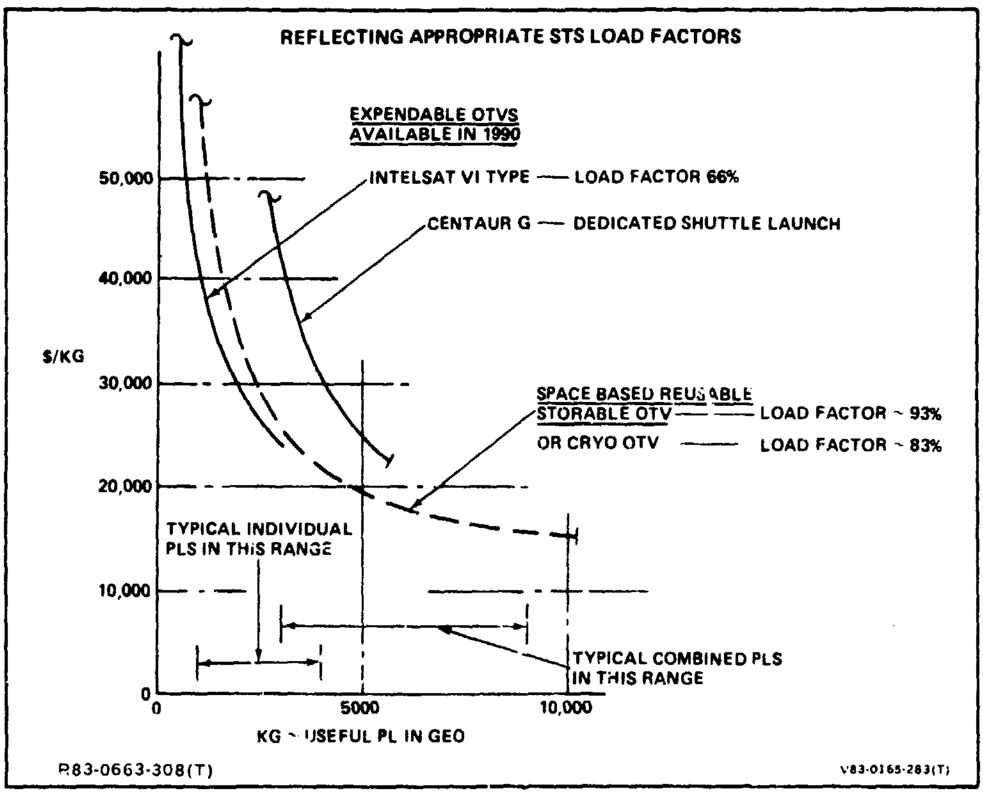

Fig. 4-7 Cost ($'84) of Ground to GEO Transport

• EXPENDABLE VS. REUSABLE SPACE BASED OTVS

• (ALL COSTS IN '84 $ M)

	'93	'94	'95	'96	AVG ANNUAL SAVING
▶DoD TRAFFIC					
EXPENDABLE OTVS	424	258	104	273	
REUSABLE, SPACE BASED	254	184	82	191	
SAVING	170	74	22	82	87
▶CIVIL TRAFFIC					
EXPENDABLE OTVS	594	822	627	690	
REUSABLE SPACE BASED	383	544	422	459	
SAVING	211	278	205	231	231

COMBINED AVERAGE SAVINGS $ 318 M/YR

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Fig. 4-8 Cost for Transport of Satellite, Ground to GEO

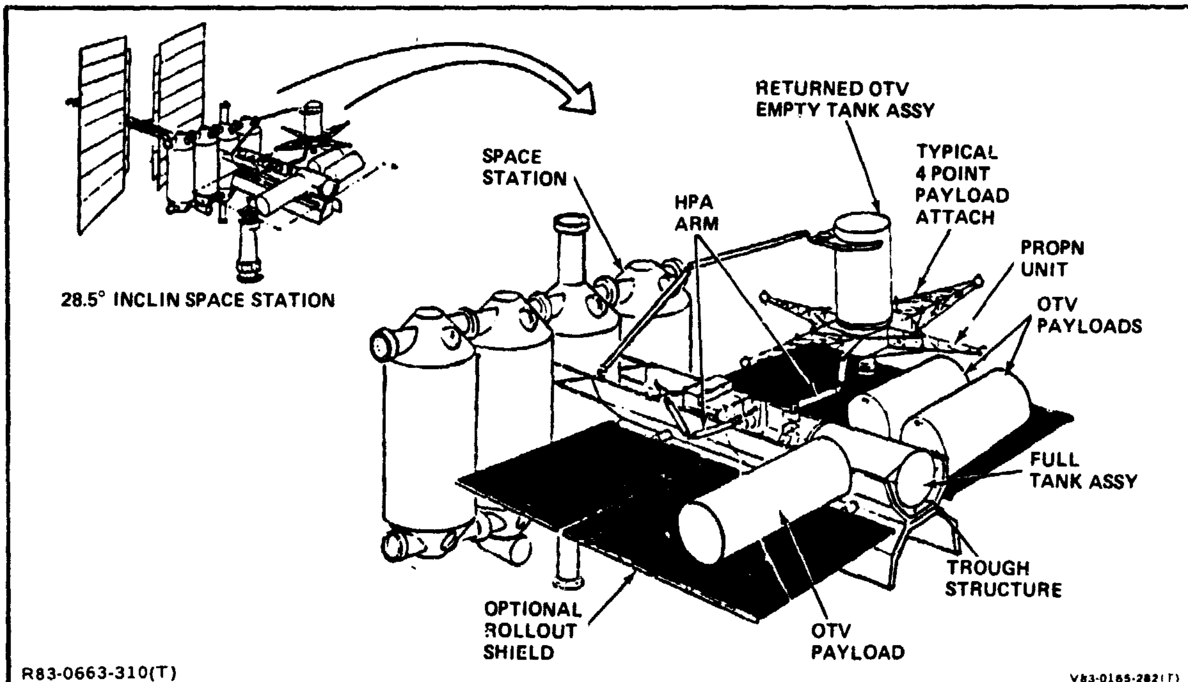

Fig. 4-9 28.5° Inclin Space Station Transport Harbor & Military Payload Assy Area

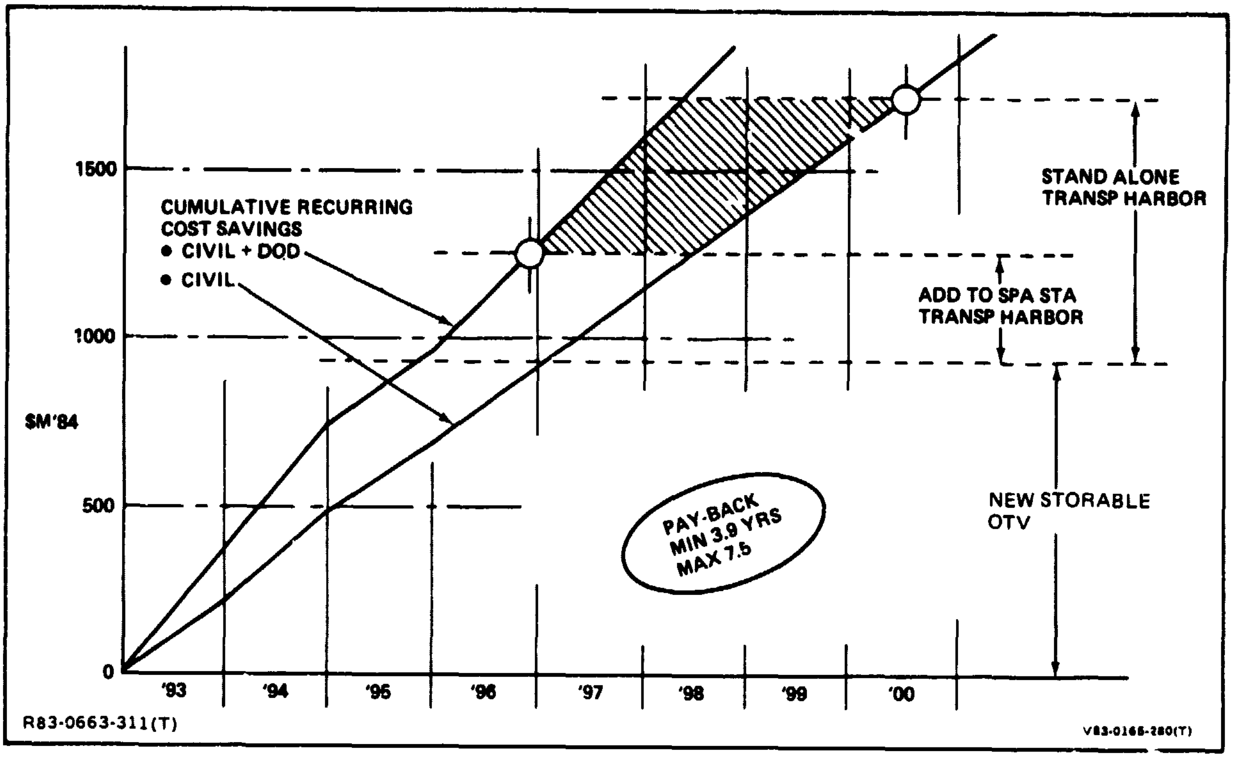

Fig. 4-10 Pay Back Period for New OTV & Transport Harbor

OTV PROPELLANT SELECTION	LESS PROPELLANT NEEDED WITH CRYO HIGHER SHUTTLE LOAD FACTOR WITH STORABLE	EQUAL GROUND-TO-GEO COSTS
	LOWER FRONT END COST WITH STORABLE	
	DEPART-ON-DEMAND WITH STORABLE	
NEW OTV COSTS	OPERATING COST SAVINGS $300M/YR AVG	
	INVESTMENT PAY-BACK 4 TO 7 YRS	
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Fig. 4-11 Reusable Space Based OTV — Propellant Choice & Cost Summary

shirt-sleeve environment or by EVA. The number of servicing opportunities for free-flying (non-formation flying platforms/satellites) are limited. About six such servicing/refurbishment opportunities have been defined for the time period from 1990 to 1995 for the Space Station Baseline Mission Model. This is mainly due to the fact that most payloads have been integrated with the Space Station. Most satellites are designed to be used and discarded following their useful life (or earlier should they fail). For expensive satellites, this should not be the case in the future. Instead, we should develop systems where we can reservice, repair and checkout satellites, restoring them to useful life in the same way that we repair our automobiles and keep them rolling on our highways. The first demonstration of such a repair will occur in the spring of 1984 when the Solar Maximum Mission (SMM) which is in orbit now and had a failure of its guidance and control (G&C) module, is brought to the Shuttle, and the faulty equipment replaced on orbit by the Shuttle. The SMM is the first satellite designed for on-orbit servicing and this feature will make it possible to restore the satellite to good health. High fidelity mock-up demonstrations of replacing this G&C module have been simulated at Grumman's Large Amplitude Space Simulation facility (Fig. 4-12). Satellite Servicing pays off particularly for large observatory satellites. One illustration of this is the Advanced X-Ray Astrophysics Facility that NASA plans to have operational by 1990. The practical potential is there for replacement of equipment to maintain the facility and to upgrade its capability at appropriate times. It is estimated that there is a $200M savings for such a satellite over a 10-year time-period. Why not do the servicing from the Shuttle? It costs more than three-times as much because supporting equipment, jigs, etc, can be left on-orbit with the Space Station instead of being transported back and forth by orbiter, which adds further cost each time the servicing is required.

4.1.4 Observatory

The fourth major area for high payoff of the Space Station is that of performing observatory class functions. Such an observatory might be attached to the Space Station as shown in Fig. 4-13 with appropriate vibration isolation so that the delicate instrumentation and telescopes may be pointed earthward or toward the heavens with reasonably high accuracy. Now we have provided a manned observatory with a pointing capability equal to or equivalent to any manned facility on the ground. It is outside the earth's atmosphere, which disturbs many of the astrophysical measurements, and also in such a situation that much of the earth's

- SATELLITE SERVICING/ASSEMBLY STATION
  - RESERVICE
  - REPAIR
  - CHECK-OUT
  - ASSEMBLY

	INITIAL CAPABILITY
– RESERVICE	√
– REPAIR	√
– CHECK-OUT	√
– ASSEMBLY	

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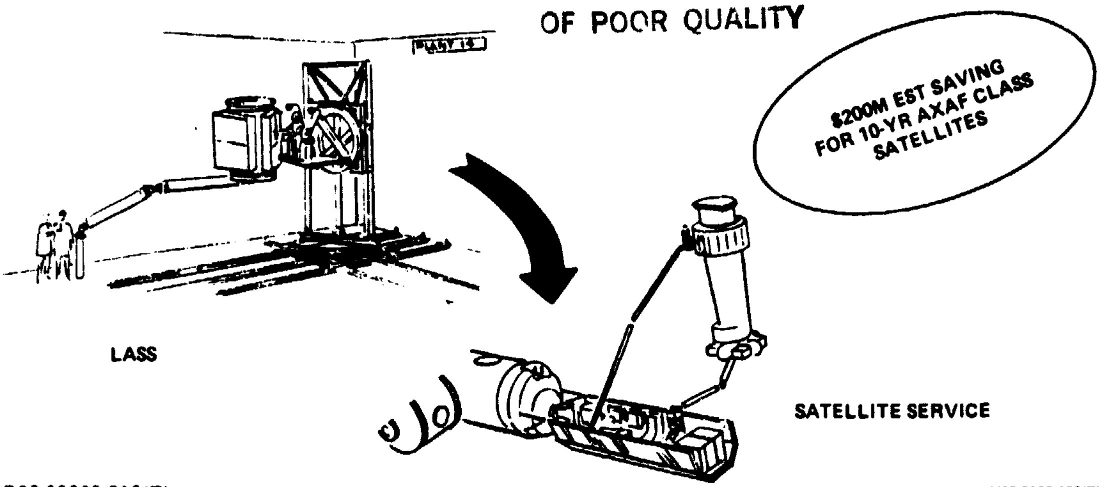

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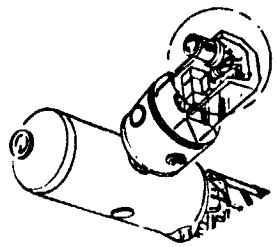
Fig. 4-12 Satellite Servicing/Assembly

- OBSERVATORY
  - ATTACHED-VIBRATION ISOLATED
  - FREEFLYER

	INITIAL CAPABILITY
– ATTACHED-VIBRATION ISOLATED	√
– FREEFLYER	



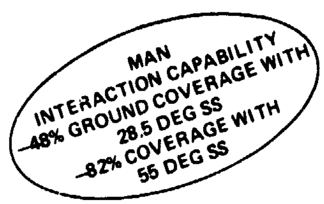


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Fig. 4-13 Observatory

own surface may be observed. How much of the earth is observed depends on the orbit inclination into which the Space Station is placed. One inclination which has been considered is 28½ deg, the inclination of Cape Kennedy. If the Space Station were to be in that inclination, the observatory would be able to cover almost half of the earth's surface as the satellite orbits our earth. With higher inclinations, more of the surface is covered. For instance, at an inclination of 55 deg more than 80% of the surface is covered and, if the orbiter were to be close to 90 deg, all of the earth's surface would be covered. The observatory function can also incorporate free flyers (that is, separate satellites flying in formation with the Space Station, which transmit their measurements by RF or Laser Link back to the mother ship, Space Station, for analysis and reprogram and/or command of free flyer experiments).

4.1.5 Industrial Park Concept Materials Processing

Studies performed have indicated that materials processing in space offers both technical and economic advantages over earth-based manufacturing procedures. Not only are higher quality products produced in the space environment, but also a significantly higher product yield results when processing materials in a near zero-gravity field. Both these factors, together with an expected increase in the market demand for the many products identified, suggest an industrial park be developed as part of the Space Station complex.

Two concepts have been considered for development of a Space Station industrial park. One concept assumes the baseline Space Station is enlarged both volume/mass and power generation capability to support an integral buildup of furnaces needed to produce the large quantity of materials needed through the year 2000. The furnaces would be installed within pressurized enclosures to allow for material put-through and furnace servicing in a shirt sleeve environment. Advantages of this concept is that the Station would grow into a high density structure and thereby offer a lower gravity environment than smaller size stations. It would also simplify logistics scheduling in that man and materials would be continuously in place and readily accessible at any time.

Disadvantages of this concept become evident as the processing requirements evolve to inordinately large volume or power generation needs that require non-moving or rotating systems to keep disturbance forces at a minimum.

A second concept considered for the development of an industrial park is the use of a series of free flying laboratories brought on-line incrementlv as a function of evolving processing needs. Each of the laboratories would be identical in design and sized in accordance with prescribed pressurized volume and power requirements.

Advantages of this concept include the fact that the free flyer units can be totally dedicated to the materials processing function and thereby be designed solely on the basis of those functional requirements. For example, free flyers can be maintained in an inertial attitude hold throughout their operational sequence and therefore be designed using fixed solar array panels rather than articulated panels as would be needed with a local vertical oriented Space Station base.

Factors to be considered that weigh on the acceptability of this concept are listed in Fig. 4-14. Included are the number of free flyer units that may be required in the higher or peak activity years and the frequency with which they are to be tended. It is hoped that the free flyer units could be placed into drifting trajectory paths that would return to the Space Station at their required servicing frequency. Consideration thus must be given to the ballistic coefficient variations that can result and the maneuvering strategies that are to be implemented.

- NUMBER OF FREE FLYER UNITS
- FREQUENCY OF TENDING
- EFFECTS OF BALLISTIC COEFFICIENT DIFFERENCES
- NAVIGATION REQTS/MANEUVERING STRATEGIES
- SEPARATION/BERTHING CONCEPTS
- PROPELLED/CONSUMABLES REQTS

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Fig. 4-14 Free Flyer Laboratories – Co-Orbital Considerations

For this study, a baseline free flyer laboratory consisting of a pressurized cylindrical section 12 ft in diameter by about 30 ft long and incorporating two solar panels which provide 22 kW of usable electrical power was used. This laboratory configuration is shown in Vol II, Book 2, Part I.

To estimate the number of free flyer units needed within the industrial park in the 1990s, a list of the materials processing requirements was compiled in terms of number of furnaces and power requirements. These lists of requirements were compiled in terms of two groupings, materials processing which require tending in longer time intervals (that is 11 days or more), and materials which require tending in shorter time spans.

Figure 4-15 summarizes the information for materials processing requiring longer tending intervals. For example, shown are the number of furnaces and the cumulative power needs for each of the productions of mercury-cadmium-telluride,

MATERIAL PRODUCED		CALENDAR YEAR '90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000	G-LEVEL (MAX)	TEND FREQ
HgCdTe	NUMBER OF FURNACES	–	1	2	4	6	7	8	9	10	11	11	10^{-5}	11
	CUM PWR RQMTS (kW)		3.5	7	14	21	24.5	28	31.5	35	38.5	38.5		
BULK GaAs	NUMBER OF FURNACES	-	1	1	1	2	2	2	3	4	4	5	10^{-5}	11
	CUM PWR RQMTS (kW)	--	7	7	7	14	14	14	21	28	28	35		
PROTEIN CRYSTALS	NUMBER OF FURNACES	–	–	1	2	3	4	5	6	6	7	8	10^{-3}	21
	CUM PWR RQMTS (kW)			1	2	3	4	5	6	6	7	8		
	TOTAL CUM PWR RQMTS	–	10.5	15	23	38	42.5	47	58.5	71	73.5	81.5		
	NUMBER OF FREE FLYERS REQD	0	1	1	2	2	2	3	3	4	4	4		

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Fig. 4-15 Materials Processing – Free Flying Industrial Complex Group 1, Frequency of Tending of 12/24 Days

(MCT) bulk galium arsenide, and protein crystals. These materials have been grouped within one category not only because of their compatible servicing frequency intervals but also because the g-levels required for their processing are within a common range.

Shown in the figures are the total cumulative power requirements for the processing of all three materials. As indicated, these power requirements grow from 10.5 kW in 1991 to 81.5 kW in 2000. Since each free flyer is capable of providing

2? kW of power, it is noted that the free flyer industrial complex would have to grow to at least four units to meet the production demands in the year 2000.

Figure 4-16 shows the same information for the remainder of materials to be processed in space. This grouping requires a g-level of 10^{-5} to 10^{-3}, and collectively requires a power requirement of almost 40 kW by the year 2000. On this basis, another two free flyer units could be brought on line to satisfy the processing needs of these materials.

MATERIAL PRODUCED		'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000	G-LEVEL (MAX)
		CALENDAR YEAR											
THIN FILM GaAs	NUMBER OF FURNACES	–	–	–	–	–	–	1	2	2	3	3	10^{-3}
	CUM PWR RQMTS (kW)	–	–	–	–	–	–	6.5	13	13	19.5	19.5	
ISOENZYME SEPARATION	NUMBER OF FURNACES	–	1	2	2	4	4	6	6	8	8	10	10^{-2}
	CUM PWR REQMTS (kW)		0.4	0.8	0.8	1.6	1.6	2.4	2.4	3.2	3.2	4	
BIOLOGICALS	NUMBER OF FURNACES	1	1	1	1	1	1	1	1	1	1	1	10^{-3}
	CUM PWR RQMTS (kW)	0.7 ←										→ 0.7	
X-RAY TARGET	NUMBER OF FURNACES	–	–	–	1	1	1	1	1	1	1	1	10^{-3}
	CUM PWR RQMTS (kW)				15	15	15	15	15	15	15	15	
LATEX SPHERES	NUMBER OF FURNACES	–	–	1	1	1	1	1					10^{-3}
	CUM PWR RQMTS (kW)			1	1	1	1	1					
TOTAL CUM PWR		0.7	1.1	2.5	17.5	18.3	18.3	26.6	3.1	31.9	38.4	39.2	
NUMBER OF FREE FLYERS		S/S	S/S	S/S	1	1	1	2	2	2	2	2	

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Fig. 4-16 Materials Processing – Free Flying Industrial Complex Group 2, Frequency of Tending – 3 Days

Figure 4-17 summarizes the complement of material processing furnaces carried on each of the free flyer units, as they are brought on-line. Also shown are the frequency in which they are planned to be tended. Free Flyer No. 2, for example, carries all of the protein crystals furnaces, and, in some years, furnaces for mercuric cadmium tetride and bulk galium arsenide. It is planned to be tended in 24-day intervals and consequently must be able to automatically process the materials put through for the shorter processing times.

CALENDAR YEAR

FREE FLYER	NUMBER OF FURNACES	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000	TENDING FREQUENCY
1	HgCdTe	-	1	2	4	4	4	4	4	4	4	4	12 DAYS
	BULK GaAs	-	1	1	1	1	1	1	1	1	1	1	
	PROTEIN CRYSTALS	-	-	-	-	-	-	-	-	-	-	-	
	SYSTEM MASS (kg)		11,700	12,500	14,100	14,100	14,100	14,100	14,100	14,100	14,100	14,100	
	VOLUME RQMTS (m^3)		7.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	
	PWR RQMTS (kW)		10.5	14	21	21	21	21	21	21	21	21	
2	HgCdTe	-	-	-	0	2	3	0	1	0	1	1	24 DAYS
	BULK GaAs				0	1	1	0	1	0	0	1	
	PROTEIN CRYSTALS				3	3	4	5	6	6	7	8	
	SYSTEM MASS				10,900	13,400	14,500	11,500	13,500	11,800	12,900	14,100	
	VOLUME RQMTS (m^3)				3	11.5	17.5	5	13.5	6	10	15.5	
	PWR RQMTS				3	17	21.5	5	10.5	6	10.5	10.5	
3	HgCdTe							4	4	4	4	4	12 DAYS
	BULK GaAs							1	1	1	1	1	
	PROTEIN CRYSTALS							0	-	-	-	-	
	SYSTEM MASS							14,100	14,100	14,100	14,100	14,100	
	VOLUME RQMTS							16.5	16.5	16.5	16.5	16.5	
	PWR RQMTS							21	21	21	21	21	
4	HgCdTe									2	2	2	12 DAYS
	BULK GaAs									2	2	2	
	PROTEIN CRYSTALS									-	-	-	
	SYSTEM MASS									13,400	13,400	13,400	
	VOLUME RQMTS									15	15	15	
	PWR RQMTS									21	21	21	
5	ISOENZYME SEP	-	1	2	2	4	4	4	4	5	5	6	3 DAYS
	BIOLOGICALS	1	1	1	1	1	1	1	1	1	1	1	
	X RAY TARGET	-	-	-	1	1	1	1	1	1	1	1	
	LATEX SPHERES	-	-	1	1	1	1	-	-	-	-	-	
	SYSTEM MASS				12,910	13,510	13,510	13,210	13,210	13,410	13,410	13,610	
	VOLUME RQMTS				24.4	25.4	25.4	22.4	22.4	22.9	22.9	23.4	
	PWR RQMTS	0.7	1.1	2.5	17.5	18.3	18.3	17.3	17.3	17.7	17.7	18.1	
6	THIN FILM GaAs							1	2	2	3	3	3 DAYS
	ISOENZYME SEP							2	2	3	3	4	
	BIOLOGICALS							-	-	-	-	-	
	X RAY TARGET							-	-	-	-	-	
	LATEX SPHERES							1	-	-	-	-	
	SYSTEM MASS							11,400	11,800	12,000	12,700	12,900	
	VOLUME RQMTS							12	17	25.5	25.5	26	
	PWR RQMTS							8.3	13.8	14.2	20.7	21.1	

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Fig. 4-17 Industrial Complex Operational Sequence for Furnaces

The industrial park complex will consist of six free flyer laboratories in the year 2000, three of which will be tended in 12-day intervals, one of which is tended in 24-day intervals and two of which will be tended in three-day intervals. Figure 4-18 summarizes the operating timeframe for each of the free flyers, their tending frequency and the servicing manhours estimated to be required.

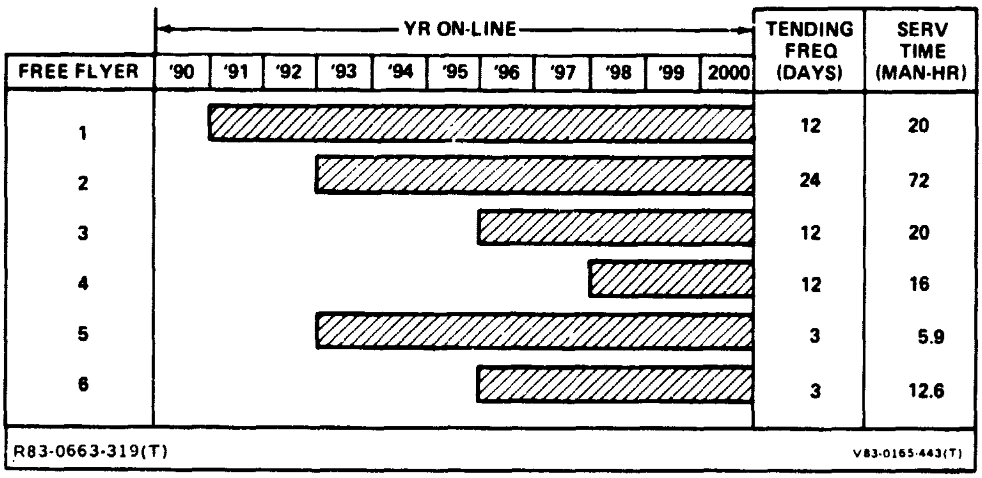

Fig. 4-18 Free Flyer Industrial Complex, On-Line Requirements

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Figure 4-19 illustrates the industrial park complex interfacing with the Space Station. A sector of space trailing behind Space Station, for example, is used for the formation flight of an industrial park complex used to manufacture and process materials on-orbit. Free flying laboratories that are periodically tended by Space Station are deployed into relative trajectory paths such that they traverse to within close proximity of the Space Station at prescribed time intervals. A small propulsion module, such as the Proximity Operations Vehicle (POV), which uses a non-contaminating cold gas propulsion system, is used to initially deploy and retrieve the free flying laboratories as they drift within the vicinity of the Space Station.

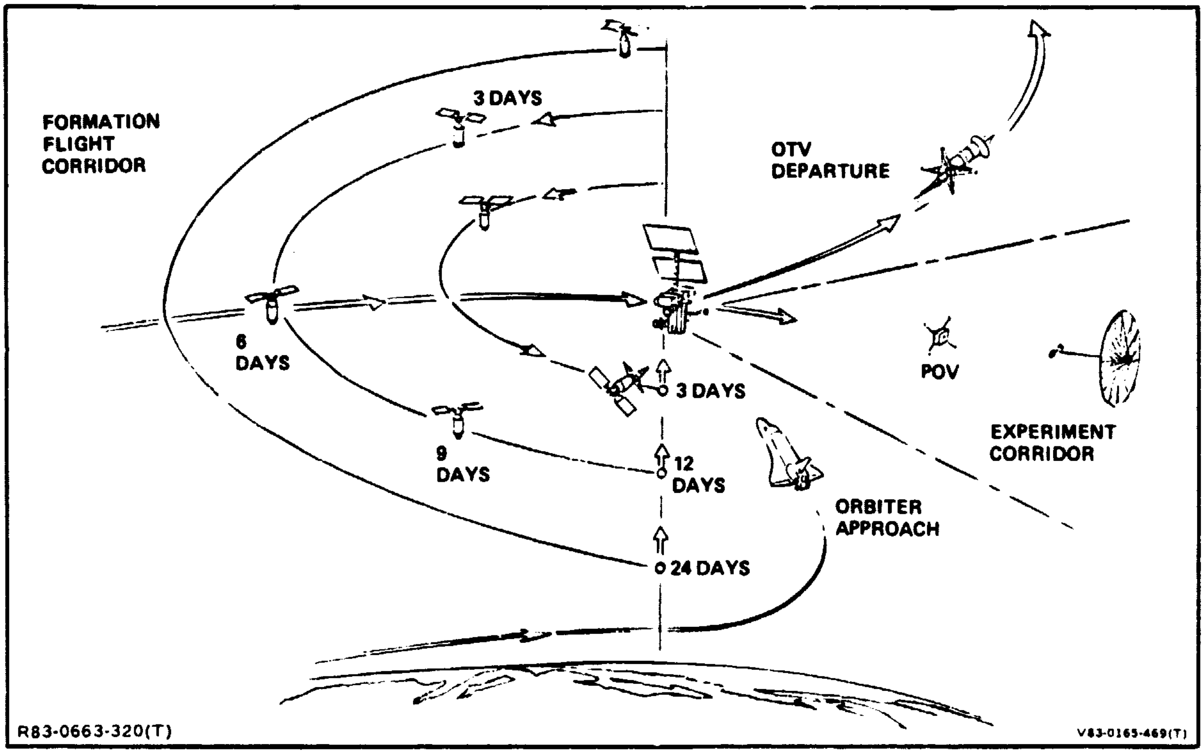

Fig. 4-19 Formation Flight & Logistics Corridor

Analysis has shown that in the year 2000, about six free flying laboratories would be required to produce the types and quantities of on-orbit materials estimated to be marketable. The free flyers would have a tending frequency at the Space Station of once every three days, once every 12 days or once every 24 days, and be cycled such that only one would arrive or depart at the Space Station on any given day. To set up this flight formation corridor would require a region about the Space Station bounded by a few kilometers above and below and extending behind to about 2000 km. Within this corridor, as many as five free flying laboratories would be detached from Space Station and in free flight.

Figure 4-20 illustrates a schedule of free flyer returns to the Space Station. As shown, the schedule assumes each free flyer is returned in accordance with the servicing/tending frequency, but staggered such that only one free flyer is returned to the Space Station on any given day.

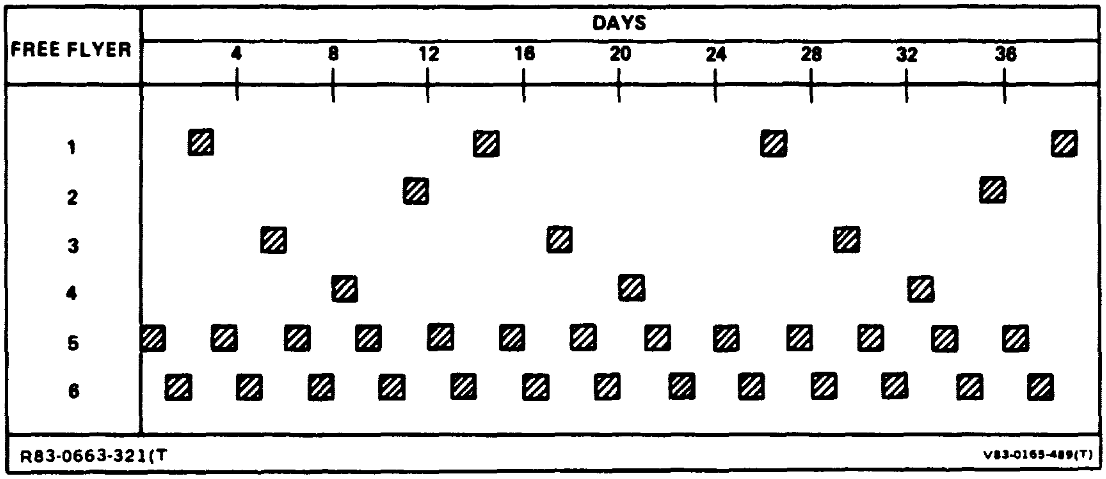

Fig. 4-20 Schedule – Free Flyer Return to Space Station

4.2 POLAR ORBIT PLATFORM ARCHITECTURAL REQUIREMENTS

High inclination missions include the following categories: solar terrestrial, global environment and resource observation.

Because a number of earth resource sensing instruments operate best in a sun-synchronous orbit with low sun beta angle, the platform is required to operate in this orbit.

The number of Shuttle flights per year strongly influences the architecture of the polar Station/Platform. The mission payloads at polar inclination would benefit greatly (in terms of scientific value and in reduced experiment/equipment costs) with a permanent manned presence. However, since the total mass/year to polar orbit for the identified civil missions only requires approximately two Shuttle flights/year, providing for a continuous manned presence could require as many as two additional Shuttle flights/year (assuming a 90-day crew cycle). Certainly the additional cost (approximately $170M/year) for continuous manned operations would be difficult to justify.

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4.3 SYSTEM REQUIREMENTS

The overall Space Station and platform activity level determines the requirement for Shuttle Logistic flights, electrical power, number of crewmen and data processing requirements. Activity associated with orbital transfer vehicles depends on the needs of geosynchronous orbit satellites. Orientation and pointing requirements are derived from the individual instrument needs.

4.3.1 Mission Servicing Operations

4.3.1.1 Low Inclination Space Station - The 28.5 deg Space Station mission operations are shown in Fig. 4-21 with potential servicing frequency indicated. External payloads SIRTF and Starlab are planned as Shuttle sortie missions that will be transferred to the Space Station when it becomes available. However, Starlab IOC could be in 1990; therefore, operations could commence from the Space Station. SIRTF may be modified to perform the Infrared Spectroscopy Mission (ISM); therefore, one year has been allowed between the termination of SIRTF operations and the initiation of ISM. High Resolution X-ray and gamma-ray Spectrometer (HRS) and Planetary Spectroscopy Telescope would also commence operations in the Shuttle payload bay if the Space Station is not available. Most of these missions probably

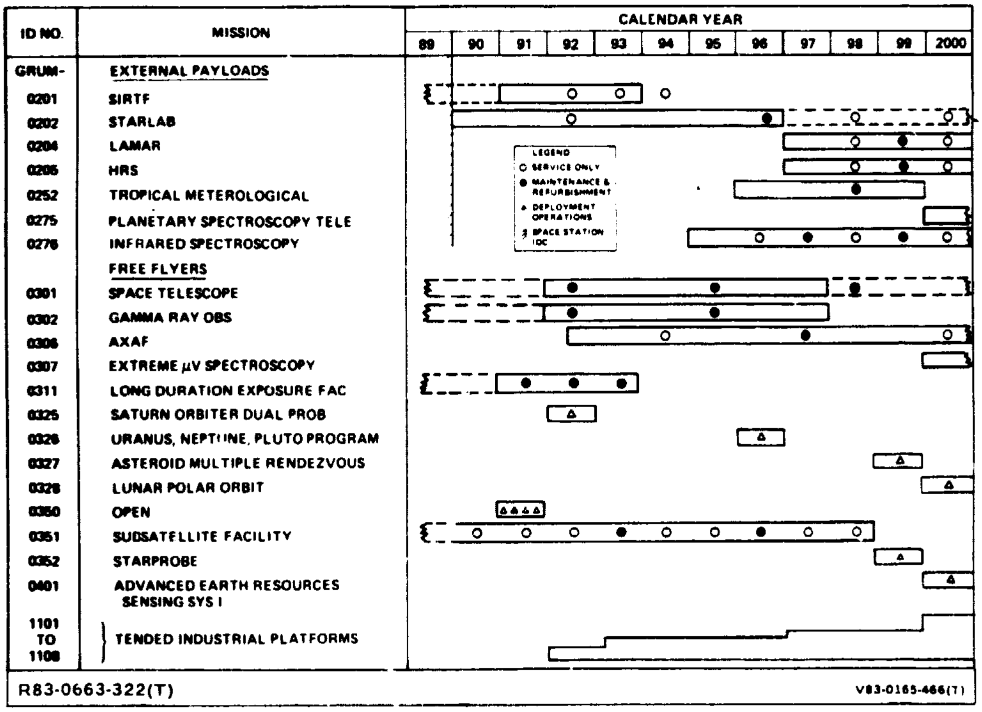

Fig. 4-21 28.5° Inclination Baseline Model Mission Servicing Operations

will continue beyond the year 2000, depending on priority of the yet-to-be-identified new missions, data accumulated and operability of the instruments. The Tropical Meteorlogical Mission (a new set of instruments) operation is shown for three years, but this could very easily be extended.

Three of the free flyers shown on Fig. 4-21 (Space Telescope, Gamma Ray Observatory and Long Duration Exposure Facility) are already in operation when Space Station comes on the scene. Subsatellite Facility initially operates from the Shuttle; later it will be launched, operated and retrieved by Space Station. The AXAF and Extreme UV Spectroscopy will be supported in orbit from the Space Station. A number of missions trojectories are beyond the reach of Space Station based operations, and could possibly be supported by Space Station only during launch/deployment operations. These missions must also be included during budgetary analysis. Several tended industrial platforms will be operated by Space Station and require frequent retrieval, servicing and deployment by Space Station; increasing number of platforms are illustrated by the stepped bar in the figure.

4.3.1.2 **Polar Orbit Platform** - The Polar Orbit Platform missions are shown in Fig. 4-22 with potential servicing frequency indicated. Most of the missions listed are external payloads (the reason for platform). It seems reasonable that missions that are to be operated near the time of platform IOC (i.e., 1994), would commence operation on the platform. The Auroral Manned Observation Platform is a new mission identified herein. The other missions have been previously identified in published reports, although the names may not be familiar (i.e., Renewable Resources Payload & Eposodic Events Detection). Eposodic Events Detection Mission uses similar instruments as the Renewable Resources Payload with the additional capability of a bore-sighted optical system with many sensors slaved to it. Maybe these two missions could be combined. Most of the missions shown in Fig. 4-22 will continue to operate beyond the year 2000.

The Advanced Operational Meteorological System, listed as a free flyer, is a companion to the similarly manned platform payload. The Windsat Mission and the Advanced Operations Meteorological System are shown requiring servicing every two years.

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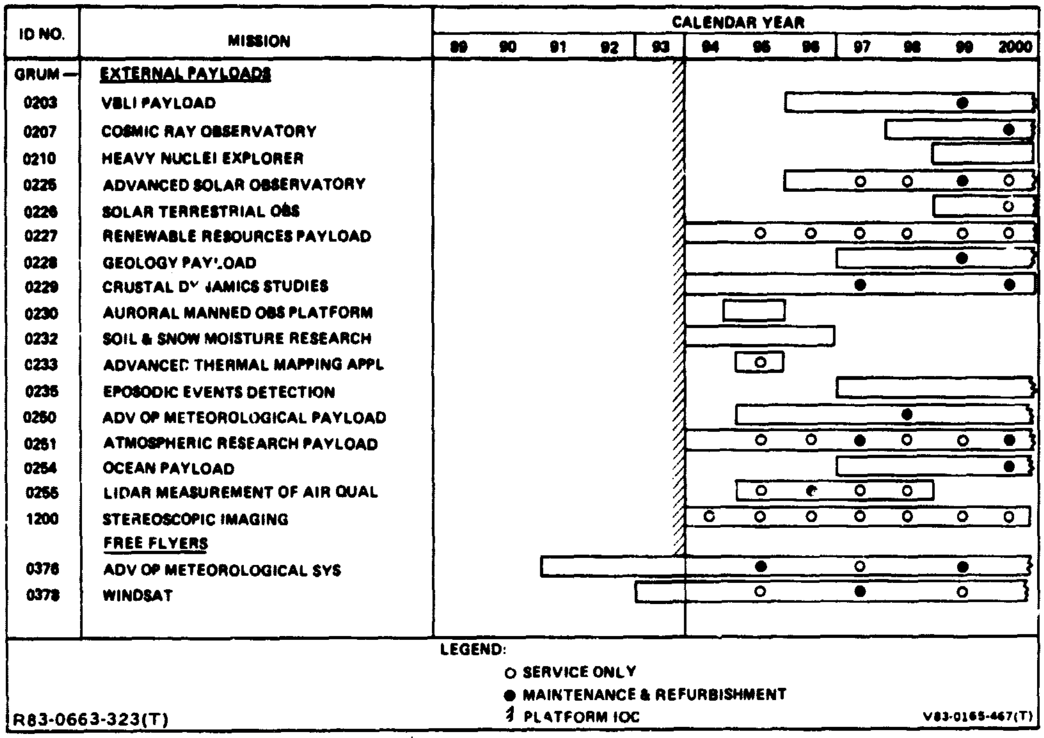

Fig. 4-22 Polar Orbit Baseline Model Mission Servicing Operations

4.3.2 Shuttle Logistic Flights

The number of Shuttle flights to the 28.5 deg inclination Space Station and the Polar Orbit Platform were determined by adding the mass to orbit per year of mission instruments, consumables, replacement components, etc, and the Space Station new additions, upper stages, consumables, replacement components, etc. The results were previously discussed and presented in Fig. 4-1.

4.3.3 OTV Flights

The civil and DoD traffic to GEO in terms of numbers of payloads and weight of payloads were derived for the 10-year period 1990 through 2000 (see Fig. 4-4). These payloads were then manifested through the 28.5 deg inclination Space Station (Fig. 4-23), assuming a storable OTV. The civil activities require an average of five OTV flights per year and the DoD payloads require one and one-half more OTV flights per year.

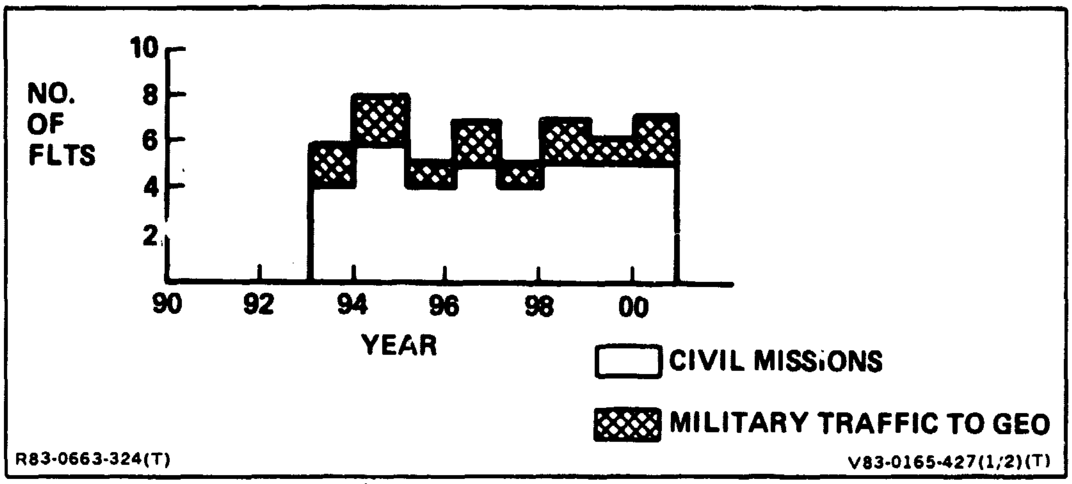

Fig. 4-23 OTV Flights

4.3.4 Electrical Power Requirements

The average electrical power required for mission activities on the low inclination Space Station is shown in Fig. 4-24. Commencing in 1990, the Station should provide 4 kW of power that must be increased to 34 kW by 1996 to support baseline mission activities. Power needs were totalled from individual mission operations and categorized in the following disciplines: Planetary; Material Sciences; Commercial R&D; Life Sciences; and Astrophysics.

Commencing in 1994, commercial R&D requires 50% of the mission power; this is due to the high power needs of material processing.

The average electrical power required for mission activities on the Polar Platform is shown in Fig. 4-25. Beginning in 1994 the platform should provide 2 kW of power that must be increased to 22 kW by 1999, to support baseline mission activities. Power needs were totalled from individual mission operations and categorized in the following disciplines: Solar Terrestrial; Commercial; and Global Environment and Astrophysics. Solar Terrestrial activities are dominant in terms of power consumption, using 65% of the total mission requirement.

If the Space Station is required to provide power for an industrial park, then the power requirements increase dramatically, as shown in Fig. 4-26.

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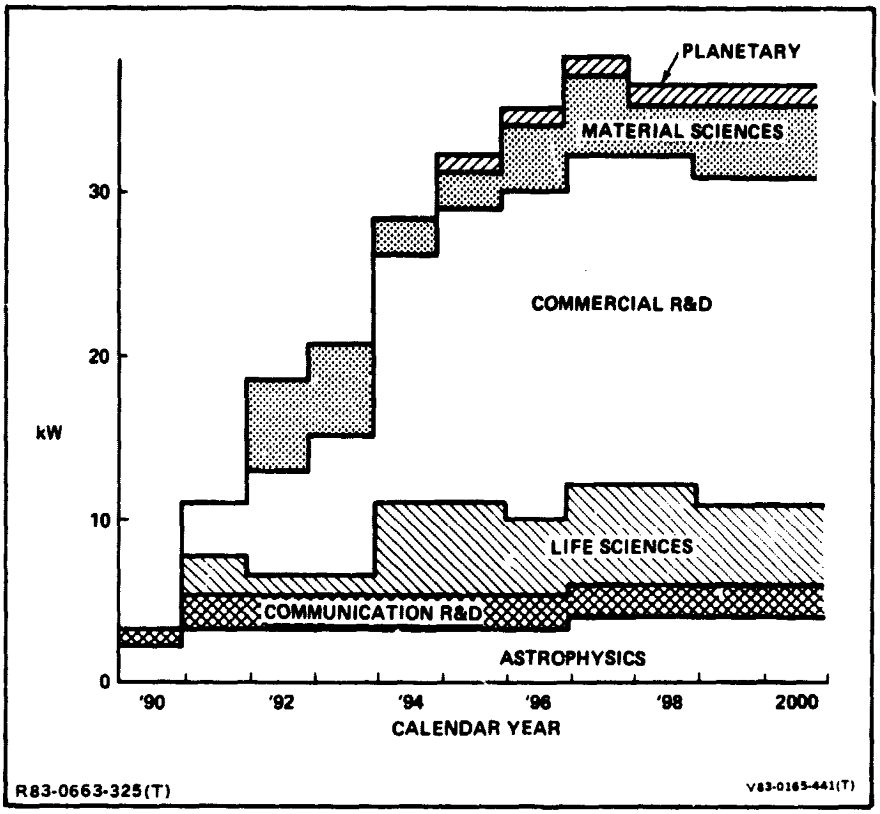


Fig. 4-24 Average Electrical Power Requirements – 28.5° Inclination Space Station

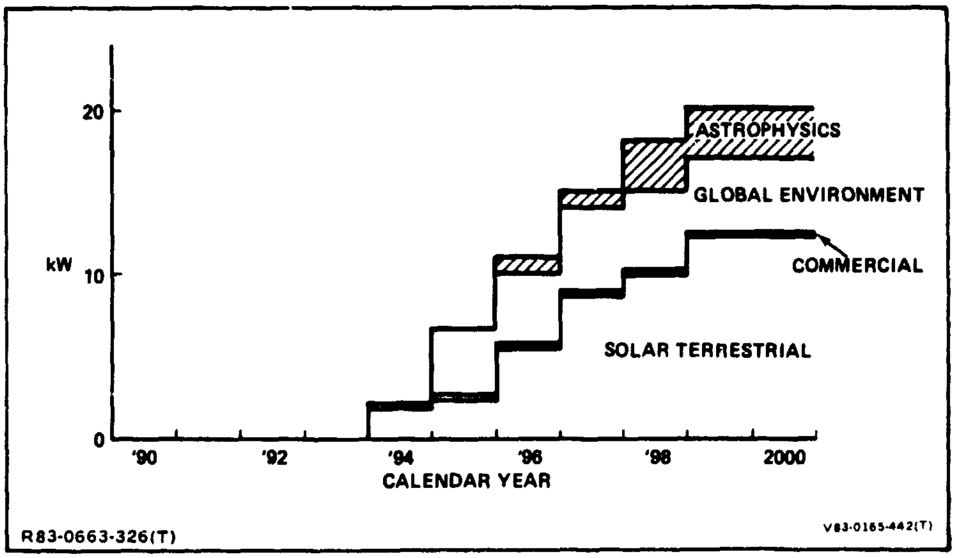


Fig. 4-25 Average Electrical Power Requirements – Polar Platform

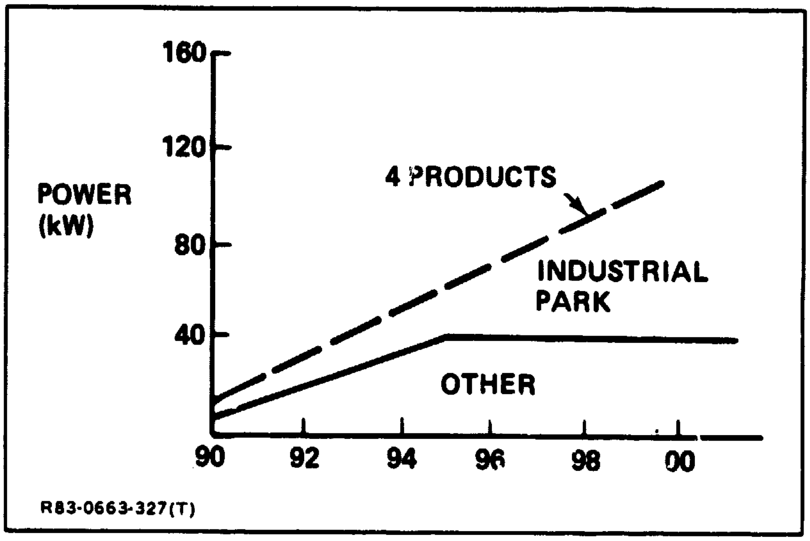


Fig. 4-26 Power Requirements

4.3.5 Crew Requirements

We analyzed crew operations associated with the Space Station and mission equipment. These were totalled for various categories of missions, and are illustrated in Fig. 4-27. Although science and application missions require the most manpower of the categories shown in the figure, the buildup of the crew is modest, from two initially in 1990 to nine in 1997.

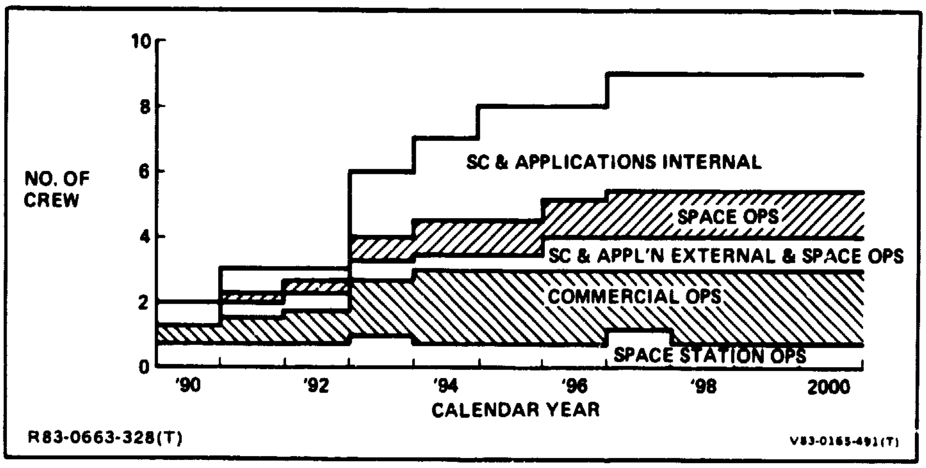
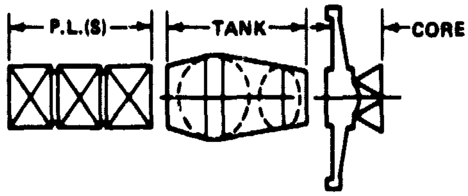


Fig. 4-27 28.5° Inclination Baseline Mission Model Crew Size

Crew time per year to operate material processing furnaces is provided in Subsection 3.2. Analysis of satellite servicing operations for a typical satellite, the AXAF, is contained in Subsection 3.3. The operations and crew manhours associated with Orbiter and OTV turnaround are shown in Fig. 4-28.



	CREW NO.	MAN-HOURS
TURN AROUND OF OTV AT SPACE STATION		
• RENDEZVOUS & DOCK	2	5
• SAFE–DETACH, DRAIN, PURGE, STORE TANK	2	10
• SCHEDULED MAINT. ON CORE	3	60
• UNSCHEDULED MAINT. ON CORE	1	20
• ASSY FRESH TANK TO CORE	2	10
• MATE P.L.(S) TO OTV	2	30
• CHECK-OUT	3	30
• SEPARATION & TRANSFER	2	5
TOTALS		170
TURN AROUND OF ORBITER AT SPACE STATION		
• RENDEZVOUS & DOCK	1	2.5
• UNLOAD & STOW CARGO ON STATION	2	40
• LOAD RETURN CARGO IN ORBITER	2	20
• CHECK-OUT (BY ORBITER CREW)	–	–
• SEPARATION & TRANSFER	1	2.5
TOTALS		65

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Fig. 4-28 Crew Size & Number of Work Shifts for OTV & Shuttle Turnaround at Space Station

4.3.6 Pointing Requirements

Most missions have multiple instruments to gather data. Some missions have instruments with different viewing requirements and pointing accuracy. The baseline missions instrument pointing accuracy for various viewing directions for the low inclination Space Station are plotted on Fig. 4-29, and those for the Polar Platform are plotted on Fig. 4-30. Both figures have broken vertical lines to indicate the Dornier instrument pointing system (IPS) accuracy requirement of 0.5 arc-sec and

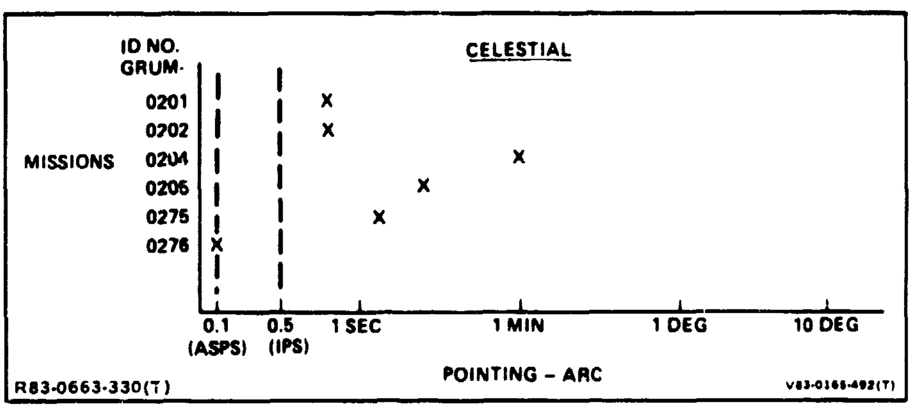

Fig. 4-29 28.5° Inclination Baseline Model Pointing Requirements

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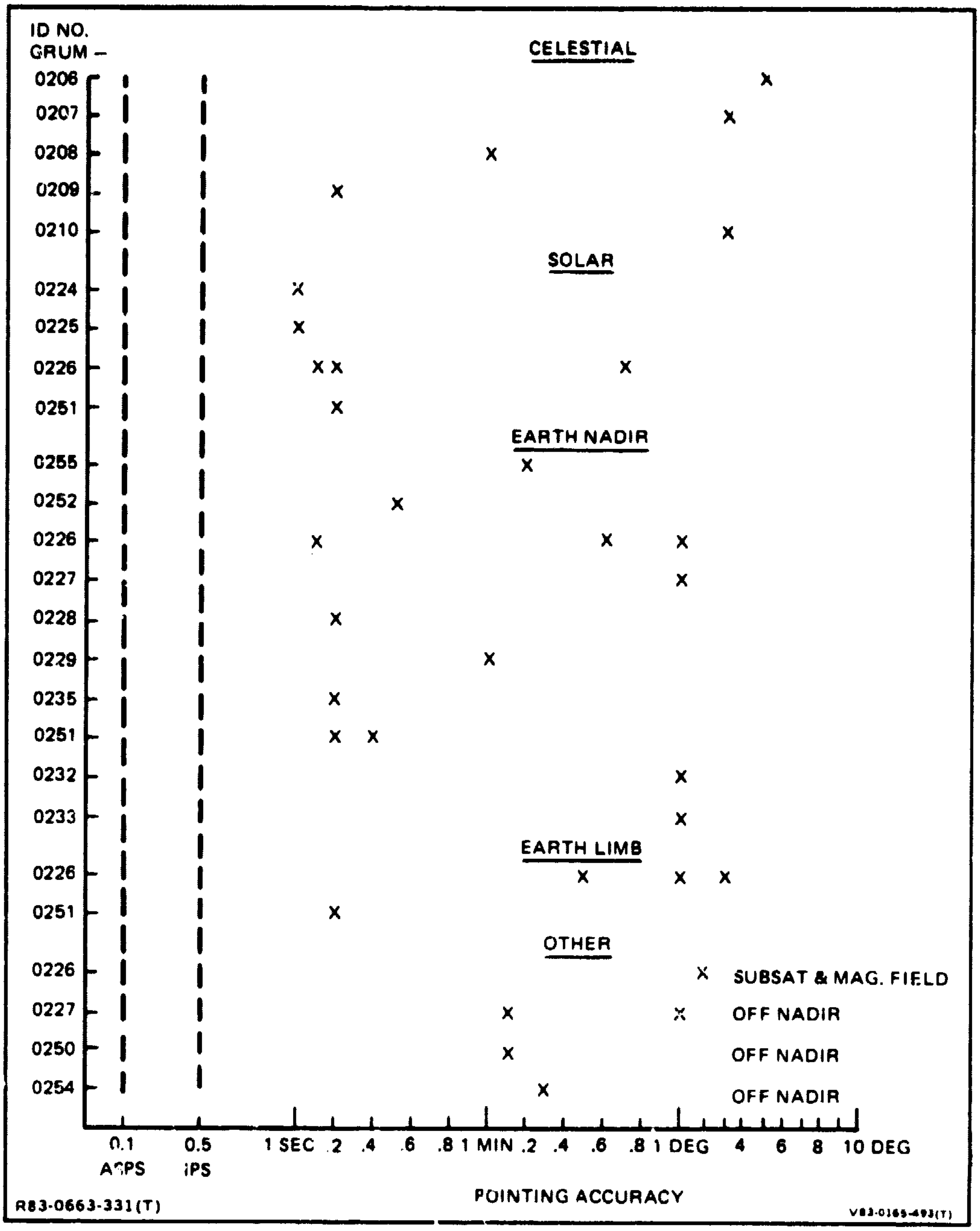

Fig. 4-30 Polar Orbit Baseline Model Pointing Requirements

the Sperry annular suspension and pointing system (ASPS) vernier of 0.1 arc-sec. The IPS is adequate for all instruments except the Infrared Spectroscopy (Fig. 4-29, GRUM0276). This could use the ASPS, if indeed such accurate pointing is required. Most of the instruments require pointing in the range from 1.0 arc-sec to 1.0 arc-deg.

4.3.7 Data Requirements

This topic has been studied by General Electric Company under subcontract to Grumman. Book 2, Part II contains mission implementation concepts for the data management system, internal communications and ground segment areas.

5 - MISSION-RELATED SENSITIVITY ANALYSES

The Baseline Mission Model (described in Section 2) formed the basis for establishing the mission-related requirements (Section 4), which in turn drove the Space Station architectural development.

Two elements of the Baseline Model that strongly influenced the mission-related requirements were as follows:

- The Baseline Model did not include Military missions (except for the Military traffic to GEO)
- A Baseline Model of total traffic to GEO (including commercial, science and application, and military) was established.

The sensitivity of the mission-related requirements to variations in these two Baseline elements is discussed in the following subsections.

5.1 Military Missions

The Baseline Mission Model included all the civil missions that survived the evaluation/screening process, plus the military traffic to geosynchronous orbit (discussed in Section 2). All other projected military missions (described in Volume II, Book 4) were not included in the Baseline Mission Model. The major purpose for treating most of the military missions on an incremental basis was to provide both NASA and the military with complete visibility as to the effect of the military missions on the integrated mission-related requirements and subsequent Space Station architectural development.

The evolutionary 28.5 deg Space Station can be a base of operation for military R&D missions that are described in Volume II, Book 4. The resulting integrated (civil plus military) requirements for the 28.5 deg Space Station are summarized in Fig. 5-1. The number of Shuttle flights, for example, indicates the breakdown for the military traffic to GEO, which is part of the Baseline Mission Model, plus the increment to accommodate the military R&D missions.

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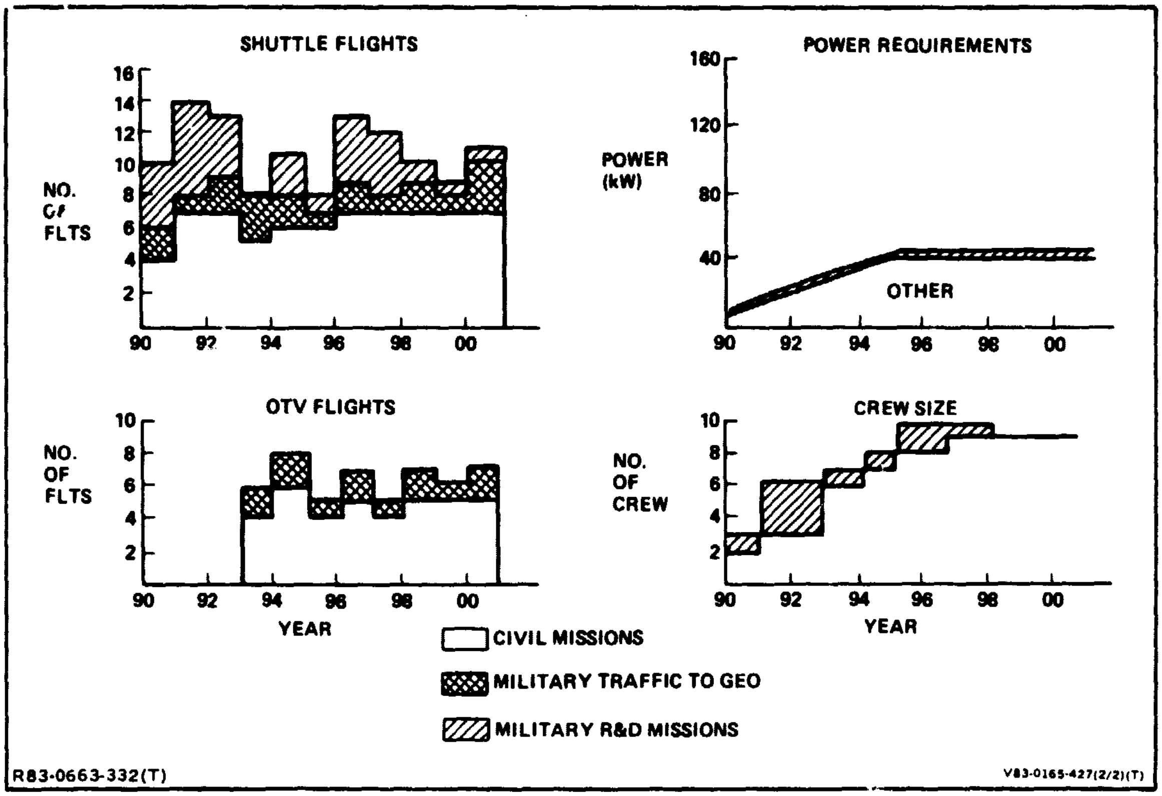

Fig. 5-1 28.5° Space Station Integrated Requirements

The results (Fig. 5-1) indicate that for the significant mission-related requirements namely transport, electrical power, and crew size, the baseline Space Station can accommodate the incremental requirements of the military R&D missions with minimum impact. The average electrical power requirements (maximum of 3100 kwh/year) represents less than a 2% increase in the average mission equipment power requirements and can be accommodated within the present baseline. The integrated crew requirements show a more rapid buildup than was required for the civil missions alone. The maximum crew size required for the Baseline Mission Model was nine. The integrated (civil plus military) requirements shows the crew size building up to a total of 10 starting in 1995. This increased requirement could probably be accommodated by adjusting total integrated crew workloads.

The Baseline Polar Station is a man-tended platform in a 370-km 97-deg inclination sun synchronous orbit. The military missions to polar orbit are described in Volume II Book 4.

A summary of the integrated (civil plus military) mission-related requirements at 97 deg inclination, are contained in Fig. 5-2. The number of Shuttle flights per

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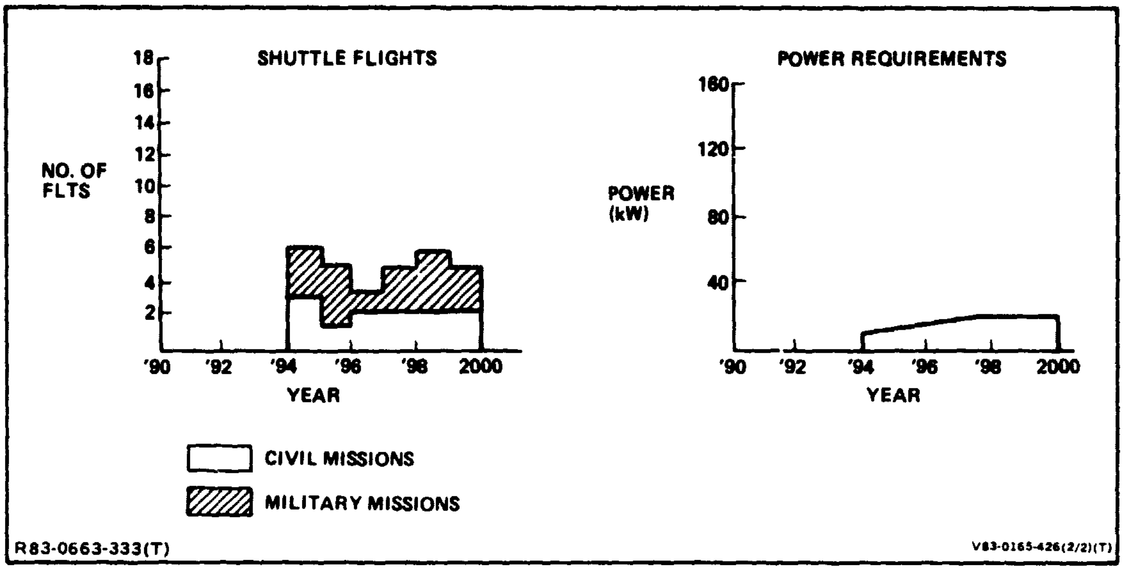

Fig. 5-2 97° Space Station Integrated Requirements

year for the civil missions (Baseline Mission Model) strongly influences the architecture of the 97 deg Station. The civil mission payloads at 97 deg would benefit (in terms of scientific value and in reduced experiment/equipment complexity) with a permanent manned presence. However, since the total mass/year to polar orbit for the identified civil missions requires an average of two Shuttle flights/year, providing for a continuous manned presence could require two additional Shuttle flights/year (assuming a 90-day crew changeout). Certainly the additional cost (approximately $170M/year) for continuous manned operations would be difficult to justify. Consequently the baseline was established to be a man-tended platform that would be visited as often as twice a year.

However, when the military traffic to polar orbit is integrated with the civil traffic, the total number of Shuttle flights is four/year or greater, and a continuous manned presence becomes viable. Consideration would have to be given as to whether military Space Shuttle launch schedules could be adjusted to permit proper phasing with the polar platform.

The baseline average electrical power requirements (Fig. 5.1-2) grows to 20 kw, which should accommodate any incremental military requirements.

5.2 TRAFFIC TO GEOSYNCHRONOUS ORBIT

The satellite traffic to GEO for the Baseline Mission Model is summarized in Fig. 5-3. This traffic model was used to perform a tradeoff study as to whether a

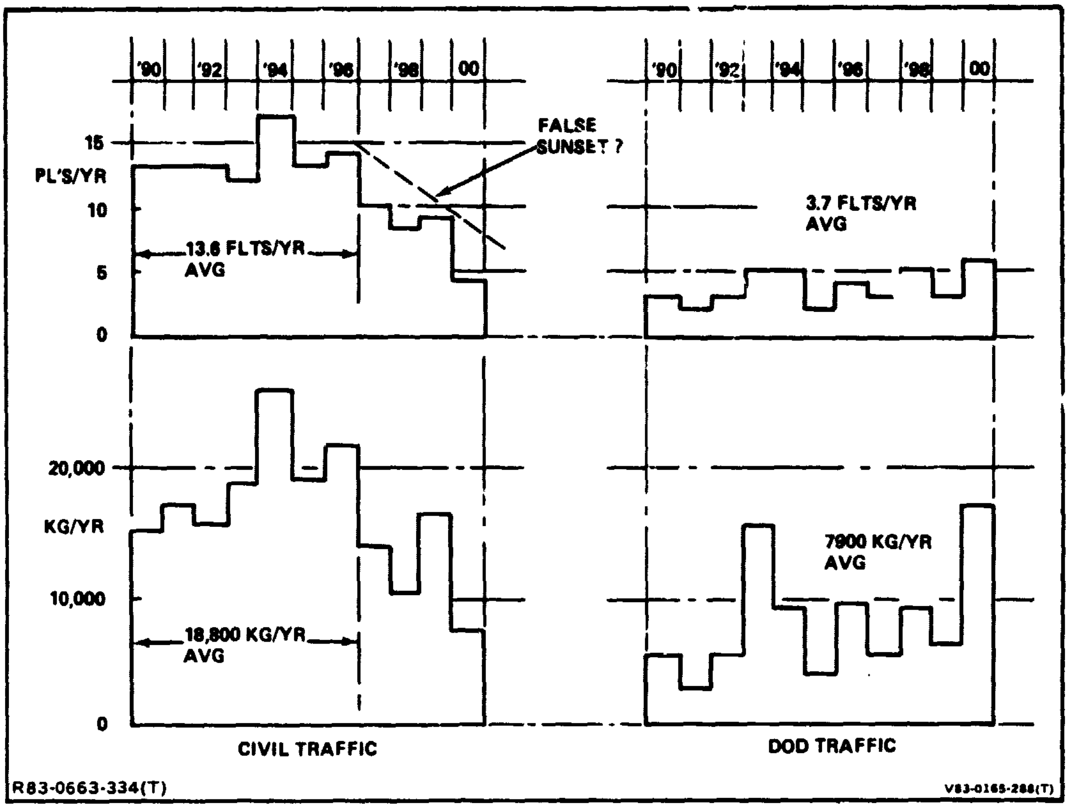

Fig. 5-3 Satellite Traffic to GEO Through 28.5°

transport harbor in concert with a reusable Orbital Transfer Vehicle (OTV) is competitive cost-wise with expendable stages for transport to GEO. The results of the study (reported in Section 4) showed that the payback period was between 3.9 and 5.4 years for the Baseline Model, and the transport harbor/OTV was incorporated as part of the Space Station architecture.

Increasing the traffic rate would, of course, reduce the payback period and make the transport harbor even more viable. At approximately three-times the Baseline traffic rate, the transportation harbor must be enlarged to handle the increased OTV/satellite traffic.

If the baseline traffic rate were reduced by 30%, the payback period would increase to between 5.5 and 7.5 years, and the economic viability of the transport harbor would become marginal. If the baseline traffic rate were reduced by 50%, the transport harbor could not be economically justified.